*Survey Results &*
***RECOMMENDATIONS***

# Operating Procedures For Shrimp Farming

GLOBAL AQUACULTURE ALLIANCE

# *Operating Procedures for Shrimp Farming*

Global Shrimp OP Survey Results and Recommendations

**Global Aquaculture Alliance**
**St. Louis, Missouri, USA**

**Operating Procedures for Shrimp Farming**


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# *Global Aquaculture Alliance*

The Global Aquaculture Alliance is an international, nonprofit trade association dedicated to advancing environmentally and socially responsible aquaculture. GAA recognizes that the culture of fish, shellfish, and other aquatic organisms is the only sustainable means of increasing seafood supply to meet growing food needs. GAA promotes sustainable aquaculture through its Best Aquaculture Practices standards, international conferences, bimonthly *Global Aquaculture Advocate* magazine, and other activities.

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# *Operating Procedures for Shrimp Farming*

**Global Aquaculture Alliance**
**St. Louis, Missouri, USA**

## Global Shrimp OP Survey Results and Recommendations

**Operating Procedures for Shrimp Farming** provides a unique overview of global shrimp production practices, as well as practical recommendations for efficient and responsible aquaculture. For this landmark publication, expert authors from both the Eastern and Western Hemispheres addressed 18 topic areas and pooled their perspectives for each comprehensive section. The authors' work was then compiled by these respected technical editors.

### Editor – Claude E. Boyd

Claude E. Boyd is a professor in the Department of Fisheries and Allied Aquacultures, and the Butler/Cunningham Eminent Scholar in Agriculture and Environmental Issues at Auburn University in Auburn, Alabama, USA. His 450 publications have included research, review, and experience papers in books, scientific journals, and trade journals. In recent years, he has advised governmental and nongovernmental organizations, and private businesses on the environmental impacts of aquaculture and been involved in developing management practices to prevent negative impacts.

### Editor – Darryl E. Jory

Darryl E. Jory is the editor of the *Global Aquaculture Advocate*, the bimonthly publication of the Global Aquaculture Alliance. He is also the technical director of the Indian Ocean Aquaculture Group, an integrated shrimp producer in southern Africa. An adjunct professor of aquaculture at the University of Miami's Rosenstiel School of Marine and Atmospheric Science, Jory has edited the proceedings of special shrimp sessions at annual meetings of the World Aquaculture Society, and written articles and manuals on shrimp farming and aquaculture.

### Editor – George W. Chamberlain

George W. Chamberlain is president of the Global Aquaculture Alliance and technical director of Integrated Aquaculture International. He formerly served as president of the World Aquaculture Society and directed corporate aquaculture programs at Ralston Purina International and Monsanto Co. Chamberlain has written dozens of technical papers and edited several manuals and reports concerning shrimp and fish farming.

***The Global Shrimp OP Survey and Operating Procedures for Shrimp Farming were made possible through the generous support of:***

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# *Global Aquaculture Alliance*

## Standards, Conferences, Communications

The primary Global Aquaculture Alliance mission is to advocate responsible fish and shellfish farming as a solution to global food needs. GAA represents the entire aquaculture value chain and facilitates cooperation among its varied elements to resolve problems and maintain public confidence in aquaculture products.

Since its formation, GAA has disseminated science-based information on seafood and responsible aquaculture. It also recognizes the need for stewardship and “continuous improvement” within the aquaculture industry. GAA’s international standards for responsible aquaculture – now endorsed by major seafood buyers and retailers – have helped form constructive linkages with the greater NGO community.

GAA’s main program areas are outlined below. For additional information, please visit www.gaalliance.org or contact the GAA office.

### Best Aquaculture Practices Standards

The BAP standards, implemented through certification inspections and administration by Aquaculture Certificaton Council, Inc., provide quantitative criteria that define sustainability and food safety at aquaculture facilities. The BAP shrimp hatchery and farm standards call for worker safety, effluent limits, biodiversity protection, and controlled chemical use. The processing plant standards augment and reinforce existing HACCP plans and require traceability. BAP standards for fish will reflect similar requirements.

### Codes of Practice for Responsible Shrimp Farming

GAA’s Codes of Practice provide general guidelines for responsible aquaculture. Recognized worldwide, the codes review shrimp production technology and farming techniques that address sustainability, efficiency, and food safety.

### Annual Global Shrimp/Fish Outlook Conferences

GAA’s marketing meetings are strategic events where leading seafood buyers, producers, and suppliers come together for updates from world-recognized experts on the global supply and demand of cultured fish and shrimp. In addition, the conferences present a forum in which global players can candidly discuss current issues and generate consensus solutions.

### Communications

The Global Aquaculture Alliance provides a range of information on aquaculture. The **Global Aquaculture Advocate,** GAA’s bimonthly color magazine, presents practical information on current seafood issues, efficient aquaculture technology, and updates on GAA activities. Search the online archives or request a trial issue.

The GAA Web site, www.gaalliance.org, and Update electronic newsletter address aquaculture issues and show how aquaculture makes positive impacts in local communities. In addition, international conference presentations inform diverse audiences of GAA’s programs, positions, and important role in aquaculture.

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# *Global Shrimp OP Survey Results And Recommendations*

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# Global Shrimp OP Survey Results and Recommendations

**Claude E. Boyd, Ph.D.**

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Shrimp farming started during the second half of the 20th century with rudimentary culture practices that yielded unpredictable and sporadic production. Over time, technology improved and the industry steadily expanded (Figure 1). Shrimp farming has become a consistent and efficient means of producing high-quality shrimp at competitive prices.

Shrimp farming now accounts for about 30% of world shrimp production and 40% of shrimp exports. It offers a means of meeting the increasing demand for shrimp without overfishing natural shrimp populations.

Shrimp are cultured in many nations, but the main production centers are in southern Asia and Central and South America. The major shrimp-producing countries are China, Thailand, Vietnam, Indonesia, India, Ecuador, Mexico, and Brazil, but shrimp culture is important in many other countries, as well.

Shrimp farming provides much-needed jobs in many impoverished areas. Moreover, it is a source of foreign exchange, for most farm-reared shrimp come from developing countries and are sold in Japan, Europe, the United States, and Canada.

*Production scale and intensity vary around the world.*

## GLOBAL SURVEY

The Global Aquaculture Alliance conducted the original Global Shrimp OP (Operating Procedures) Survey of shrimp culture practices in 2001 for the following reasons:

- There was a need to identify successful practices and technologies on a global scale.
- As best management practices are further adopted in shrimp farming, data on the proportion of producers using such practices was not known.
- Although the organization and size of shrimp farms differ between the East and West, there was little detailed data on these differences.
- The opinions of producers on research and development needs within the industry would be especially useful.

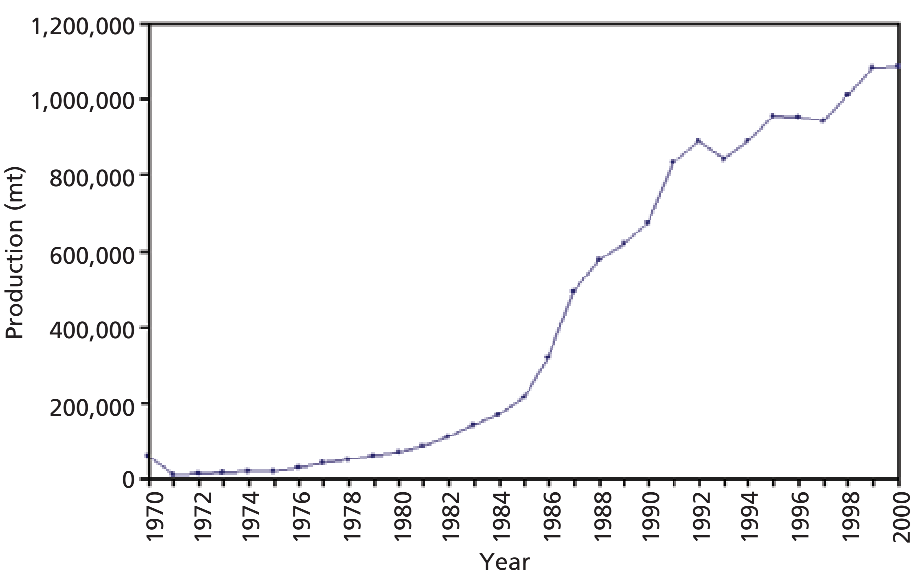


*Figure 1. Global shrimp production, 1970 to 2000.*

The online Global Shrimp OP Survey – supported by program sponsors Biofend-APC, Cargill Animal Nutrition, Grobest, INVE bv, Aeration Industries, Inc., and Zeigler Bros. Inc. – was initiated in June of 2001. Over 1,500 responses from 50 countries were received in a benchmarking effort that will likely be repeated to measure progress. In Vietnam and Thailand, direct interviews of farmers conducted by pollsters used the same questions found in the electronic survey.

*Pacific white shrimp have long been the species of choice at Western farms – and their culture is spreading.*

*Typically larger than white shrimp,* Penaeus monodon *are raised primarily in the Eastern Hemisphere.*

## PRINCIPLES, RECOMMENDATIONS

The survey was divided into 18 sections within five industry sectors. Evaluation of the survey data from each section usually was done by two experts, one from the Eastern Hemisphere and one from the Western Hemisphere. These collaborators then prepared a chapter that expanded on the survey results to explain relevant principles, suggest recommended practices, and offer further references.

Early Global Shrimp OP Survey results were briefly summarized in the *Global Aquaculture Advocate*, GAA's bimonthly magazine. Selected parts of the survey also were presented at international aquaculture meetings.

Although the survey results are now dated, they provide a baseline summary of the industry practices applied during the early years of the 21st century. Similar surveys may be administered in the future to track the evolution of global shrimp production procedures.

It is essential to recognize that this publication goes far beyond the simple reporting of survey results to explain the important principles that led to the selection of survey topics. The Global Shrimp OP Report also offers recommendations from industry experts based on current technology and practices that reflect many advances in responsible shrimp facility management.

Many of the points expressed in the survey are also addressed in GAA's Codes of Practice for Responsible Shrimp Farming, which are intended to assist in the development of national or regional codes, as well as provide direction for individual farm operators. GAA's Best Aquaculture Practices program of standards and facility certification builds on the codes of practice in a system that quantitatively evaluates responsible practices and food safety at shrimp hatcheries, farms, and processing plants around the world.

## SHRIMP CULTURE

Shrimp culture techniques differ between Asia and the Americas. In Asia, most shrimp farms are family-operated and have only a small area (less than five hectares) for production. Farms usually are much larger in the Americas.

Many Western Hemisphere farms exceed 100 hectares, and some have 1,000 or more hectares in production. Western ponds tend to be several hectares in area. Farm management usually is conducted by employees rather than the owner and family.

The major culture species in the Western Hemisphere is the Pacific white shrimp, *Litopenaeus vannamei,* while the black tiger prawn, *Penaeus monodon*, is the most commonly cultured shrimp in the rest of the world. Recently, *L. vannamei* were introduced to Asia, and their culture there is increasingly common.

Shrimp are produced mainly in earthen ponds of less than two-meter average depth constructed near the sea, bays, or estuarine systems where a constant supply of brackish water or sea water is available. Originally, ponds were filled by tidal activity, but pumps were later adopted to allow ponds to be constructed outside tidal zones.

Postlarval shrimp are stocked in ponds, raised to a marketable size, and harvested by draining the ponds. Postlarvae for stocking ponds once were supplied almost exclusively by artisans who captured them from coastal waters. This practice obviously could compete with shrimp fishing by lessening the abundance of native postlarvae for replenishing the shrimp fishery. Today, most postlarvae originate in hatcheries, but some adult spawners or broodstock are still captured from the sea. Fortunately, an increasing number of hatcheries use farm-reared broodstock.

## OVERVIEW

The intensity of shrimp production in ponds varies greatly. In extensive production, only a few postlarvae are stocked per square meter, and only a few hundred kilograms of shrimp are produced per hectare. Semi-intensive production requires stocking rates of five to 15 postlarvae per hectare, with up to 2,000 kilograms of shrimp harvested per hectare. Stocking rates usually are above 20 postlarvae per square meter, and production is over 2,000 kilograms per hectare in intensive production.

Few management inputs are made in extensive production. Fertilizer and feed must be applied to semi-intensive and intensive ponds to allow shrimp to grow to marketable size in three to six months.

*In addressing its early mistakes, shrimp farming now recognizes the value of mangroves.*

## FEED INPUTS

Only a portion of the nutrients in shrimp feed is converted to shrimp meat, and the remainder enters the pond ecosystem to stimulate phytoplankton growth. Dense phytoplankton blooms in ponds can cause low dissolved-oxygen concentration and other water quality imbalances. When daily feeding rates exceed 30 to 40 kilograms per hectare, low dissolved-oxygen concentrations often cause shrimp stress or mortality.

Thus, high rates of water exchange have traditionally been applied to avoid low dissolved oxygen in semi-intensive ponds. Both water exchange and mechanical aeration have been used to maintain water quality in intensive shrimp culture. Shrimp can be produced in ponds without water exchange, but mechanical aeration is necessary if feeding exceeds 30 kilograms per hectare per day.

Water from shrimp ponds usually has higher concentrations of suspended solids, organic matter, nitrogen, and phosphorus than the natural waters into which it discharges. Shrimp feed is the major source of the nitrogen and phosphorus, which can cause phytoplankton blooms responsible for suspended solids and organic matter.

*High-quality feeds provide both improved nutritional value and less waste.*

Feeding techniques that prevent overfeeding and wasted feed reduce nitrogen and phosphorus and improve water quality. Moreover, good feeding practices conserve shrimp feed and challenged feed ingredient sources, and reduce production costs.

Feed manufacturers also can assist in reducing nutrient inputs to ponds by producing high-quality, water-stable feeds that contain no more nitrogen and phosphorus than necessary. Particular emphasis is being given to reducing the fishmeal concentration in shrimp feeds, for this valuable resource should not be wasted.

## POND TREATMENTS

Agricultural limestone and lime have been used widely in shrimp culture to neutralize acidic water and bottom soil in ponds. This prevents stress from low pH and promotes more efficient assimilation of metabolic wastes in pond ecosystems by pH-sensitive microbial populations.

Other pond amendments – such as live bacterial inocula, enzyme preparations, zeolite, bactericides, and oxidants – also are applied to ponds to improve the environmental conditions for shrimp growth. However, the effectiveness of these amendments has not been fully verified by research.

Between crops, ponds often are dried, limed, and tilled to improve soil quality and destroy aquatic pests. In areas with a high incidence of shrimp disease, chlorine or other chemicals is applied to ponds before stocking to kill pathogens or their vectors.

Mechanical aeration can help reduce animal stress in culture ponds.

*Strict biosecurity measures and proper pond treatment between crops can minimize the impacts of pathogens.*

Disease is a major issue in shrimp farming because shrimp do not have a highly developed immune system and are susceptible to disease, especially viral diseases. The devastating effect of disease in shrimp farming was first manifested in Taiwan, where in the late 1980s, disease cut production from about 70,000 metric tons per hectare to less than 30,000 tons. The White Spot Syndrome Virus led to severe losses of farm-reared shrimp in Asia in the mid-1990s and was especially devastating when it spread to Ecuador in the late 1990s (Figure 2).

Disease problems resulted in the use of drugs and other chemicals to minimize losses. This practice has been only marginally successful, and is used less today than in the past. It is generally accepted that the best way to avoid disease on shrimp farms is to adopt the following practices:

- Stock high-health (disease-free) postlarvae.
- Reduce water exchange to prevent disease organisms or their vectors from entering via water supplies.
- Install biosecurity measures to prevent other sources of disease.
- Manage ponds to maintain good water quality and reduce shrimp stress.
- Dry pond bottoms between crops to eliminate potential reservoirs of disease.

Antibiotics use can lead to antibiotic resistance in disease organisms. Also, antibiotic residues in food constitute a potential health risk to consumers. Shrimp-importing nations have zero tolerance guidelines for some antibiotics and maximum tolerable concentrations for others. Consumers are aware of the potential risks of antibiotics and other chemicals in their food and are demanding safer products. Thus, avoidance of antibiotics in shrimp culture is a responsible, necessary measure.

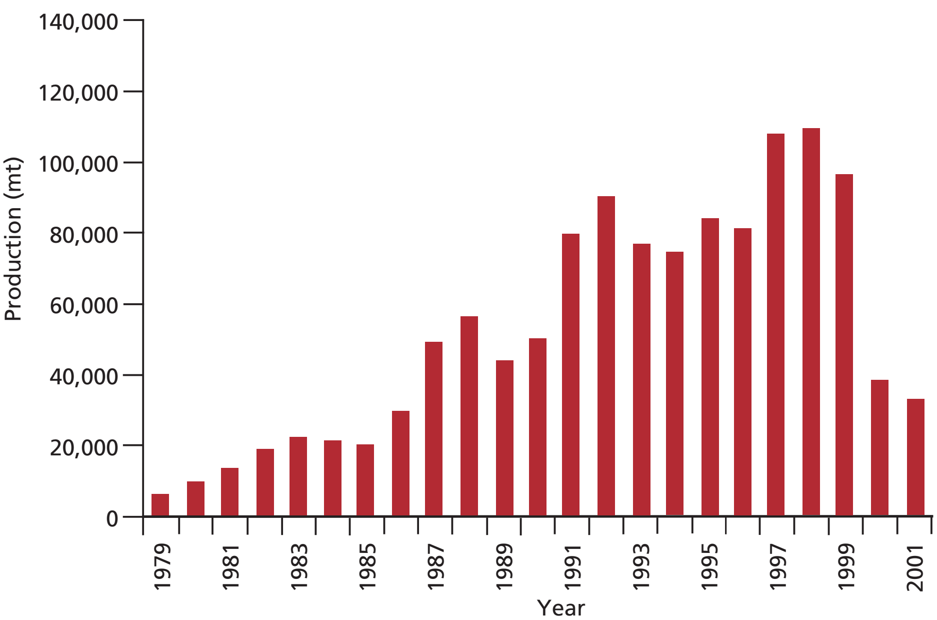


*Figure 2. Ecuadorian shrimp exports, 1979 to 2001.*

Some water supplies for shrimp farms are contaminated with suspended solids, nutrients, and industrial and agricultural chemicals. Thus, water pollution is a concern to shrimp farmers, for contaminated water can kill or stress shrimp. Contaminated water can be improved in quality if it is held in reservoirs for a few days before being added to ponds.

Because water quality is a major concern in shrimp culture, and many producers have initiated water quality-monitoring programs to evaluate incoming water and the suitability of water in ponds for shrimp growth. Good managers commonly base pond management decisions on water quality data.

*Water quality monitoring is an essential part of shrimp farming. It not only promotes a healthy culture environment, but helps control effluent problems, as well.*

## ENVIRONMENTAL ISSUES

Because shrimp farming and other types of aquaculture have become a major land use category in many nations, they have rightfully received the scrutiny of the environmental community.

Although environmental damage can and has resulted from aquaculture, some environmentalists have overstated the damage. The shrimp-farming industry recognizes its shortcomings and realizes that the complaints of environmentalists could cause consumers to reject farmed shrimp and lead governments to impose harsh regulations.

In the 1990s, mangroves were a point of contention between the shrimp industry and some environmental groups. Because ponds usually are built near water sources, they often are located in areas where mangrove forests occur, and some mangroves have been displaced by shrimp farms.

However, mangrove ecosystems are low-lying areas where it is difficult to properly construct and operate shrimp farms. Mangrove soils can be acidic, organic, or both, which results in serious water quality problems that require large inputs of liming material to correct. Vectors of shrimp disease are difficult to exclude from ponds in mangrove areas.

Furthermore, mangrove forests are considered valuable resources, and most nations have regulations that prohibit their destruction. Today, shrimp farms seldom are constructed in mangrove areas but are often situated near mangrove ecosystems.

As with mangroves, the industry is becoming increasingly proactive in modifying production practices to make shrimp farming more efficient in its use of natural resources, less harmful to the environment, and more socially responsible. Also, techniques are being developed to minimize the use of antibiotics and other potentially accumulative chemicals in hatcheries and ponds in order to assure that cultured shrimp are safe for consumers.

Through its Best Aquaculture Practices certification, which is implemented globally by Aquaculture Certification Council, Inc., the Global Aquaculture Alliance is a leader in promoting responsible practices in shrimp aquaculture. Through the work of GAA and others, shrimp producer associations, government fisheries agencies, and international development organizations are increasingly recommending that their members or clients should use better shrimp production practices.

*While farming and harvesting practices vary widely around the world, aquaculturists collectively supply a growing volume of shrimp to meet human dietary needs.*

# HATCHERY

# *Genetic Improvement*

GLOBAL AQUACULTURE ALLIANCE

# Genetic Improvement

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## Principles

During the early years of modern shrimp farming, producers were under little pressure to use domesticated stocks or develop selective-breeding programs. Only in isolated regions of the South Pacific and countries such as Brazil, Venezuela, and the United States – where the preferred shrimp culture candidates are non-indigenous – were pioneering domestication programs established. Since then, disease-induced production crises and self-imposed mandates to enhance the performance of shrimp stocks have compelled shrimp farmers to reevaluate the merits of genetic improvement through domestication and selective-breeding practices.

As part of the Global Aquaculture Alliance's international Global Shrimp OP: 2001 Survey, producers worldwide were polled in a comprehensive survey of their domestication and selective-breeding techniques. The participants included farmers, hatchery operators, broodstock breeders, and government research institutions.

The global survey revealed that the basic principles and impetus for the creation of genetic improvement programs were to enhance disease resistance, increase productivity, and reduce dependency on wild stocks. The survey highlighted disparities in the rates of progress in the genetic improvement of farmed shrimp between geographic regions and among the dominant farmed species. It also reinforced the need for increased global discussion and collaboration in selective-breeding protocols.

## Survey Results

### GEOGRAPHIC VARIATION

For this report, 62 responses from 20 countries were received. Table 1 summarizes the respondents by geographic region and the number of years producers in those nations have utilized domesticated shrimp.

While the commercial shrimp-farming industry has existed since the late 1970s, approximately 70% of the survey participants had practiced selective breeding and domestication for less than six years. Forty-two percent of the respondents from the Western Hemisphere had worked with domesticated lines of shrimp for three to five years, compared to only 9% for those from the Eastern Hemisphere. With the exception of French Polynesia and New Caledonia, shrimp farmers in the West used domesticated shrimp for considerably longer – in some cases since 1981 – than their Eastern counterparts.

*Table 1. Geographic distribution of survey respondents and number of years (until 2001) each country utilized domesticated shrimp stocks.*

| Country | Number of Respondents | Years Using Domesticated Shrimp |
|---|---|---|
| **Western Hemisphere** | | |
| Belize | 1 | 3 |
| Brazil | 3 | 20 |
| Colombia | 2 | 15 |
| Costa Rica | 2 | 6 |
| Ecuador | 9 | 8 |
| Guatemala | 1 | 3 |
| Honduras | 4 | 7 |
| Mexico | 9 | 7 |
| Nicaragua | 1 | 3 |
| Panama | 3 | 3 |
| United States | 10 | 17 |
| Venezuela | 4 | 10 |
| Total | 49 | Average: 8.5 years |
| **Eastern Hemisphere** | | |
| Australia | 3 | 6 |
| Eritrea | 1 | Unknown |
| India | 2 | 2 |
| Indonesia | 3 | Unknown |
| New Caledonia | 1 | 18 |
| South Africa | 1 | 2 |
| Sri Lanka | 1 | Unknown |
| Thailand | 2 | 3 |
| Total | 14 | Average: 6.2 years |

*Due largely to the availability of wild* P. monodon *broodstock, domestication of the species in the Eastern Hemisphere has not kept pace with genetic advances of other species in the West.*

*Some lines of domesticated* L. stylirostris *(above) have advanced past the 30th generation in captivity, although* L. vannamei *remains the most popular species of farmed shrimp in genetic improvement programs.*

This regional divergence can be attributed to the plentiful access to wild seedstock and broodstock of the preferred species (*Penaeus monodon, Litopenaeus chinensis*, and *Marsupenaeus japonicus*) that Asian farmers have traditionally enjoyed, in contrast to the Americas, where the ideal culture candidates (*L. vannamei* and *L. stylirostris*) are not indigenous to many of the principal shrimp-producing nations of the region. The absence of the preferred species obligated local farmers to adopt domestication programs to assure dependable supplies of seedstock and broodstock without the need to continuously import them.

Sixty-eight percent of the producers surveyed from the Western Hemisphere maintained domesticated stocks older than four generations in age, compared to only 33% for the East (Figure 1). The oldest lines of domesticated shrimp were in Brazil, Venezuela, Mexico, and French Polynesia. Domesticated strains of L. stylirostris exceeding 30 generations in captivity from the founding population are still cultured in Venezuela, Brunei, and French Polynesia. Brazil has a captive population of L. penicillatus – first introduced into the country in 1984 – that has also passed 30 generations in captivity.

Species that typically exhibit fast rates of growth and maturation, such as *L. stylirostris*, can produce multiple generations in a 12-month period, thus enabling growers to accelerate their domestication programs in a relatively short period of time. Most growers in the Americas culture *L. vannamei*, which according to 64% of the participants surveyed, require nine to 12 months for the female broodstock to reach reproductively active size from the egg stage. Time to maturity is, of course, influenced by ambient temperatures, rearing density, and other factors in the broodstock-rearing installations.

## BREEDING PROGRAM GOALS

Participants of the survey were asked to prioritize the goals of their breeding programs (Figure 2). The majority of the participants surveyed, especially producers in the West, stated that the development of disease-resistant or high-performance lines of shrimp were the most important goals of their breeding programs. In the Eastern Hemisphere, reduced dependence on wild shrimp stocks was also cited as a compelling motive driving selective-breeding programs.

## FOUNDING POPULATIONS

The survey revealed remarkable differences between the two major global shrimp-farming regions in the origins of founding populations used to launch their domesticated lines. All respondents from the Eastern Hemisphere indicated they acquired the parental founding stocks for their domesticated lines from wild populations of shrimp, whereas in the West, 70% of the producers initiated their domestication programs with previously existing strains of domesticated shrimp. The failure to rely on domesticated lines as founder stock in the East is a reflection of the paucity of good domesticated populations in that region and a lack of confidence in the

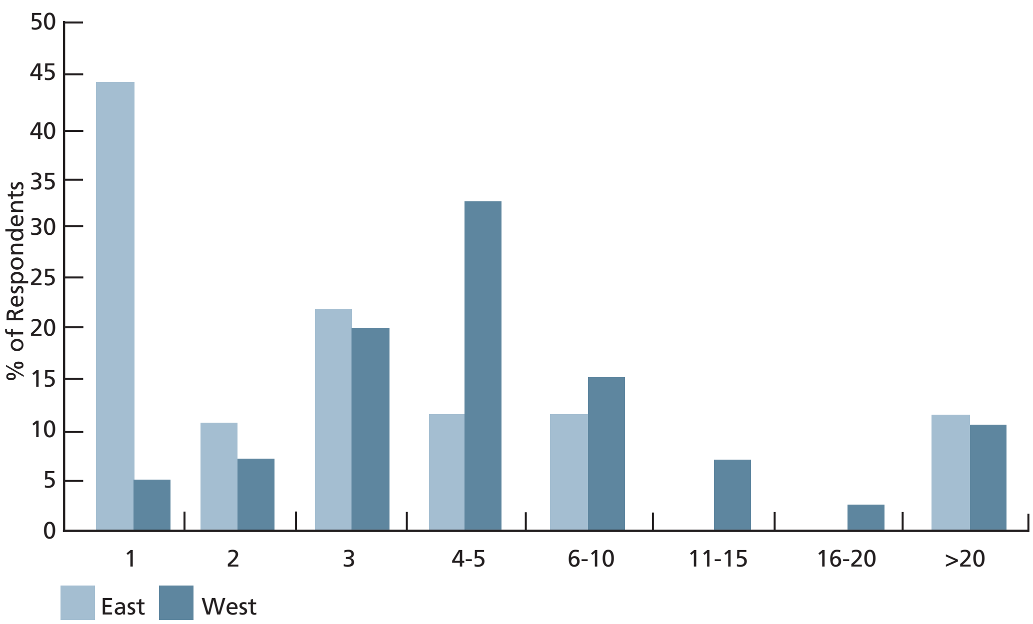


*Figure 1. Age (in generations) of domesticated stocks used in genetic selection programs.*

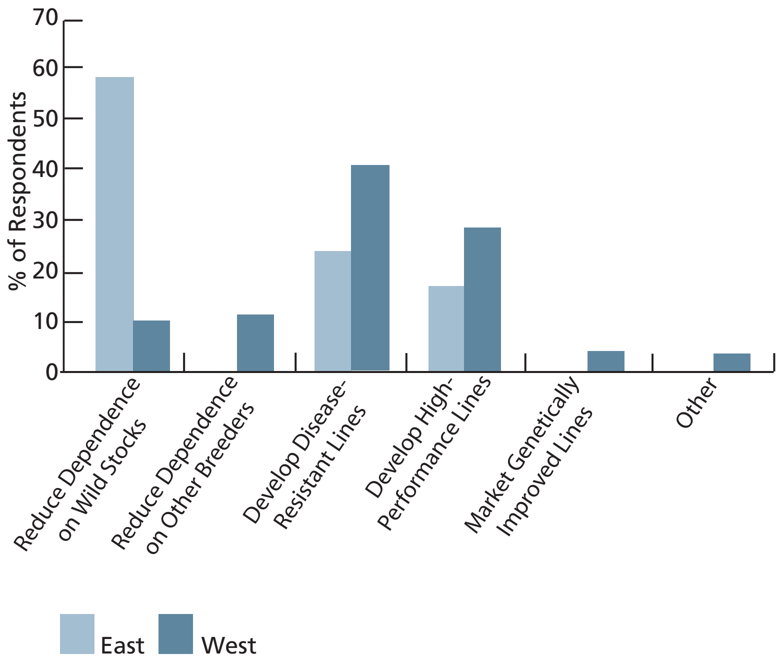


*Figure 2. Priorities for breeding and genetic selection programs.*

At present, the "Other" category would include Necrotizing Hepatopancreatitis, Gill-Associated Virus, Lymphoid Organ Vacuolization Virus, Infectious Myonecrosis Virus, and Mourilyan Virus. Ironically, a number of farms from countries in the Americas that were free of viral epizootics admitted they did not screen founding populations for viruses, a practice that could threaten their disease-free status.

The results of the survey suggested that the initial screening and selection of wild shrimp used as founder stocks for breeding programs deserve greater attention than they have received in the past to improve pathogen screening and genetic diversity of the foundation populations. Although the importance of screening founder stocks for known viral pathogens is increasingly recognized, the survey revealed that this practice is not always employed.

The failure to screen for viral pathogens and maintain ongoing monitoring for known or newly identified pathogens is perhaps the greatest threat to the success of shrimp domestication and breeding programs. Internationally recognized disease-monitoring standards must be applied to genetic improvement programs in the shrimp culture industry.

genotypic characteristics of the domesticated lines already in existence.

In the Americas, Panama was the most popular source of wild shrimp for initial stocks, followed by Mexico and Ecuador. Panama's popularity as a founder source is attributable to the perceived superior genotypic characteristics of its shrimp stocks and the fact that, until recently, the region was considered free of the most virulent shrimp viruses. Venezuela, Colombia, and the U.S. were the preferred sources for previously domesticated shrimp as founder populations, presumably due to the historical performance of their domesticated shrimp lines.

## PATHOGEN SCREENING

Initial screening of founding stocks for pathogens is imperative before introducing them into a genetic selection program. This is especially true for wild animals, whose disease status is typically unknown.

Most producers in the Americas screened their founding stocks for the presence of viral pathogens, most notably White Spot Syndrome Virus (WSSV), Taura Syndrome Virus (TSV), and Infectious Hypodermal and Hematopoietic Necrosis Virus (IHHNV) (Figure 3). WSSV, IHHNV, and Monodon Baculovirus (MBV) appear to be the main viral pathogens of concern in Asia.

## REARING, HOLDING FACILITIES

In most commercial operations, broodstock rearing and selective breeding are generally integrated, often using the same culture systems for both objectives. Production systems used to rear stocks and selected lines varied considerably, with open ponds the most common method used by respondents, particularly in the West. Tanks and covered raceways were used by 71% of the operations in the Eastern Hemisphere.

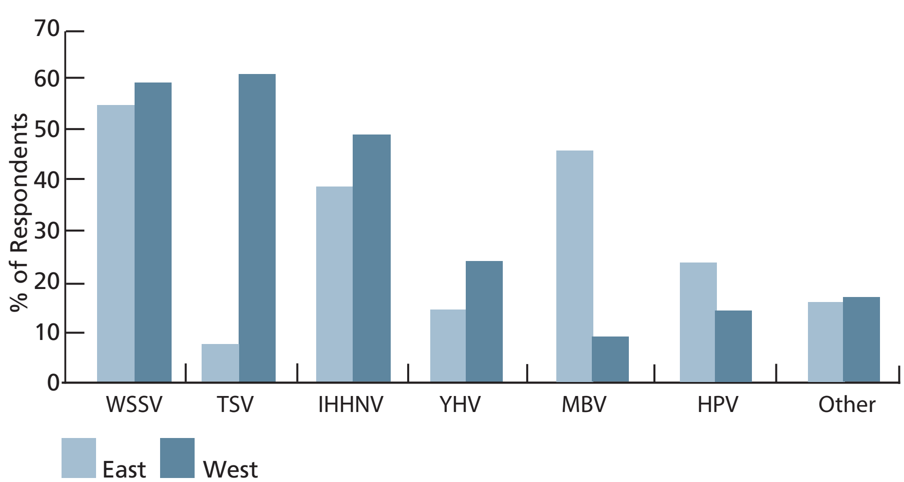


*Figure 3. Viral pathogens most commonly monitored in founding stocks.*

*Covered tanks and raceways provide biosecurity as well as greater temperature control than ponds.*

Tanks and covered raceways are more conducive to stringent biosecurity than open ponds. Not only can they be properly sealed, but covered raceways also facilitate temperature control that permits year-round rearing of broodstock in temperate and subtropical regions. Cages of 2- to 4-square-meter volume were utilized by several producers, mainly to isolate selected families prior to tagging and mixing together in larger rearing facilities.

One hectare was the most common pond size, although participants reported pond sizes ranging 0.1 to 5 hectares. Dimensions for covered raceways varied tremendously, from 13 to 800 cubic meters, although the majority of the participants selected raceways of 40 to 80 cubic meters in size.

## BIOSECURITY

Biosecurity is an important consideration when designing and operating broodstock-rearing facilities, especially when the intended recipient of the breeding stock is a hatchery that demands disease-free adults. Ideally, broodstock should be reared in an environment as free of pathogens as is economically feasible. Pathogen challenges for verifying specific-pathogen-resistant (SPR) status can be carried out in separate installations isolated from main rearing facilities.

When asked to rate the biosecurity of their selective-breeding facilities, 16% of the respondents rated their facilities not biosecure, 59% claimed moderate biosecurity, and only 25% said their facilities were highly biosecure. The latter group consisted mainly of companies that specialize in marketing specific-pathogen-free (SPF) broodstock or produce certified disease-free postlarvae. Growers using open ponds can make few claims of biosecure operation.

Increasing numbers of shrimp culturists manage their selective-breeding programs by intentionally rearing SPR broodstock candidates in pathogen-positive environments. They believe that SPR lines of shrimp should be continually exposed to the "cocktail" of viruses and bacteria found in the local environment.

Similarly, mass selection programs focused on disease resistance often rely on in situ exposure to disease to select the hardier or more resistant animals. This strategy sacrifices biosecurity and SPF status for the assurance that animals have been selected for disease resistance based on repeated challenges to endemic disease organisms.

The principal drawback to this approach is that the breeding stock that survive the disease challenges are usually pathogen carriers that can infect their offspring either via vertical transmission or disinfection failures. A well-documented example of this is IHHNV, which can be transmitted intra-oocytically from the female to her offspring and result in deformities and growth depression in affected individuals.

## SELECTIVE-BREEDING STRATEGIES

Three common selection strategies have been widely implemented in stock-improvement programs: mass/individual selection, family selection, and within-family selection. Combinations of the three techniques can also produce beneficial gains.

Mass selection is usually considered most effective when heritability is high. Under low heritability conditions, either family or within-family selection may be more useful. Despite the fact that family selection can produce more dramatic and rapid genetic gains than individual or mass selection, only around 30% of the respondents surveyed utilized some form of family selection alone or in combination with other selection methods (Figure 4).

Nearly half the survey participants relied exclusively on individual/mass selection in their breeding programs. Twenty-seven percent practiced exclusively family selec-

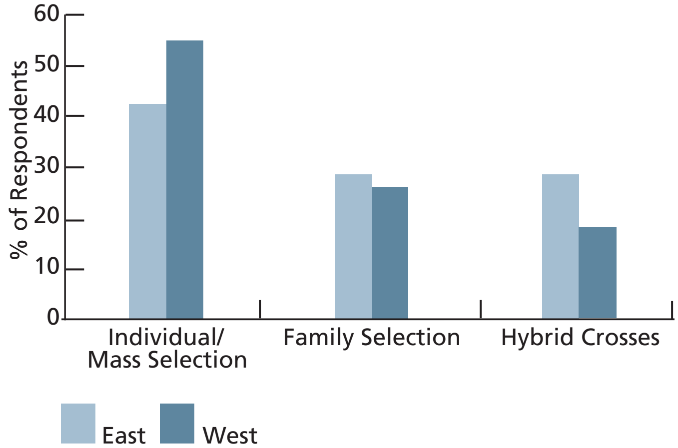


*Figure 4. Selection methods used in genetic improvement programs.*

tion, while 10% employed both methods. Hybrid crossing was employed by up to 28% of the respondents. One participant used combined family and within-family selection for the facility's family-based line.

Remarkably, there were no significant differences between the two global regions in terms of acceptance of the different selection strategies. In light of the impressive results obtained with family selection strategies in the industry, especially when used to develop specific pathogen resistance, family-based breeding strategies should be encouraged.

Selective-breeding programs often focus on pure lines, but occasionally specific trait selection within lines of shrimp can produce significantly less response than by crossing separate lines to pursue hybrid vigor. Slightly more than 50% of the respondents reported that they used only pure lines of shrimp in their breeding programs. Twenty-four percent utilized hybrid crosses, while another 24% employed a combination of pure lines, and hybrid crosses.

From the results, it was unclear which approach is superior, but the preferred strategy is most likely a combination. One caveat is that crossing domesticated lines with non-domesticated lines can precipitate undesirable gene flow and migration into the domesticated lines from the unselected stocks.

Some selective-breeding programs feature full-sib and half-sib crosses. Full-sib crosses signify sister-brother matings. Half-sib crosses usually involve crossing a male or female with multiple siblings of the opposite gender.

The survey participants whose breeding programs featured full- or half-sib crosses were equally divided between the two breeding methods. A limited number practiced both methods.

## SUCCESSFUL PROGRAM

The following is a brief description of a successful selective-breeding program currently in practice in an integrated shrimp-farming venture in Latin America.

1. Using artificial insemination, 48 half-sib crosses are performed. As a result, 48 families are formed by mating 24 males with 48 females.
2. From each spawn, 6,000 nauplii are selected phototrophically and reared to postlarvae (PL) at a density of 150 nauplii per liter in 48 individual 40-liter tanks.
3. Each of the 48 families of postlarvae is stocked in an individual cage at 400 PL per cage, placed in a large tank or pond, and fed a commercial 45%-protein maturation feed.
4. After five weeks, 150 juvenile shrimp around 1 g in size from each family are individually identified with a colored elastomer tag injected into the last tail segment. Each member of a family has the same color tag. Then all of the juvenile shrimp from the 48 families are stocked in a single tank at 144 shrimp per square meter and raised for approximately 10 weeks.
5. After 10 weeks, the shrimp are harvested, and about 30 shrimp from each family are measured and weighed. The families are ranked based on specific traits such as average weight or survival using a series of statistical analyses. The top 5% of the families are then segregated and used to produce broodstock for supplying the growout farm with postlarvae.

*Individual shrimp can be tagged with colored injectable elastomer markers.*

## MARKERS

Crossing individual shrimp is usually accomplished by artificial insemination, which 39% of the survey participants employed as part of their breeding programs. To select individual shrimp for artificial insemination, it is often necessary to distinguish the animals by marking or tagging them. Family-based breeding programs also require that each family be uniquely marked for subsequent differentiation after they are pooled in a common rearing environment.

A variety of practical implements are available for marker-assisted breeding, including eyestalk tags and injectable elastomer markers. In addition to inert tags, genetic markers such as microsatellite DNA markers, amplified fragment-length polymorphism (AFLP) markers, and randomly amplified polymorphic DNA (RAPD) markers also exist. AFLP and RAPD are multiple genetic-marker identification technologies based on polymerase chain reaction that do not require prior knowledge of the target genome.

Of the survey participants who marked their shrimp, 32% used exclusively eyestalk tags, mainly as individual identification for breeding candidates. Fourteen percent exclusively used injectable elastomer markers, primarily for separating and distinguishing families. Thirty-six percent employed a combination of the two methods. Another 14% of the respondents combined the two physical tagging systems with microsatellite DNA and AFLP or RAPD markers.

Although more costly to use than inert tags, genetic markers constitute a powerful tool for genetic improvement by linking enhanced performance characteristics like growth or pathogen resistance to specific DNA sequences. Once these unique DNA sequences have been identified and validated, rapid advances in performance enhancement are achievable. Genetic markers can also be used to identify and catalog the pedigree of shrimp derived from multiple families held together in the same culture systems, as well as fingerprinting specific populations.

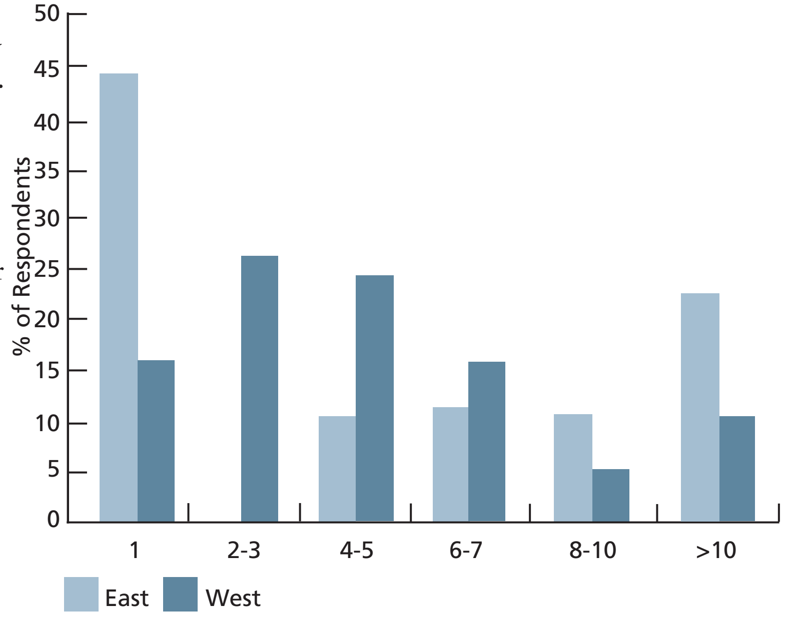


*Figure 5. Reported number of genetically distinct shrimp lines maintained within each genetic improvement program surveyed.*

## MULTIPLE SHRIMP LINES

As genetic improvement programs proliferate, practitioners often expand the number of genetically distinct shrimp lines that drive each program. Multiple domesticated lines enable producers to create hybrid crosses in a search for hybrid vigor and enhanced performance. Selection for different traits – for example, growth rate, disease resistance, and tolerance to high or low salinities – often results in different commercial lines, each with its unique genotypic and phenotypic characteristics.

Nearly 45% of the selective-breeding programs in the Eastern Hemisphere operated with only one shrimp line (Figure 5), whereas half of all programs in the Americas maintained between two and five genetically distinct shrimp lines. Twenty percent of all respondents surveyed claimed to have eight or more shrimp lines in their genetic improvement programs, although it is unknown whether the lines are indeed genetically diverse.

## FAMILY SELECTION

In genetic selection strategies utilizing family selection, the number of families created in each breeding session generally influences the rate of genetic gains achieved by the program. Among practitioners of family selection, a consensus did not exist for the optimal number of families to maintain in a selective-breeding program.

Among growers in the East, almost all practiced family selection. However, the programs were limited to 6 to 50 families per year (Figure 6), with the majority creating just six to 10 families annually. In contrast,

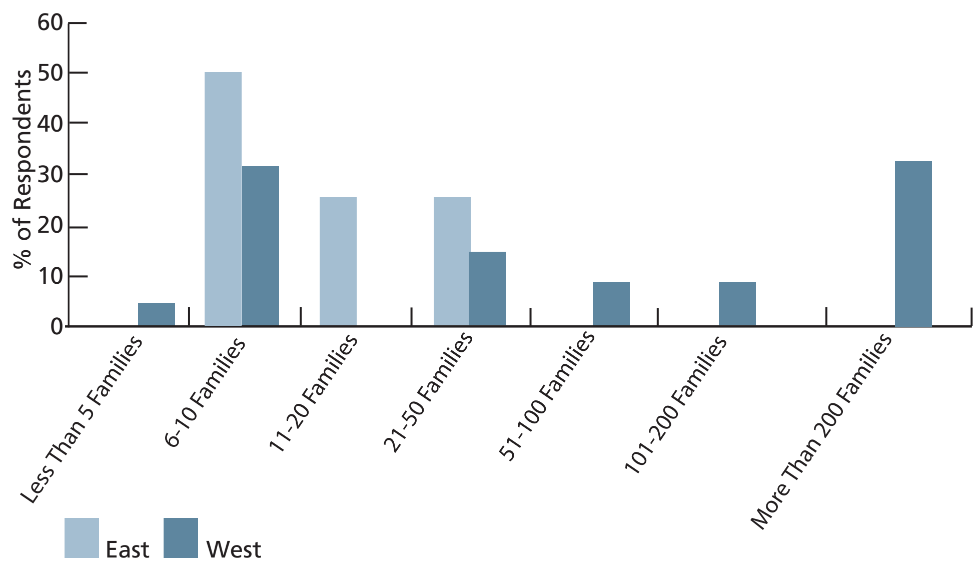


*Figure 6. Number of families produced annually in genetic improvement programs that utilize family selection.*

approximately 30% of the participants from the Western Hemisphere created and evaluated more than 200 families per year.

One very successful genetic improvement program in the Americas maintained a breeding nucleus of 70 families and created 384 full-sib families during the course of its family-based selective-breeding program. The program routinely evaluated 25,000 to 30,000 animals per batch from the 70 families.

Of the survey participants who practiced family selection, 58% created and evaluated more than 20 families a year. One high-profile breeding program produced 80 genetically distinct families twice each year, and has evaluated more than 500 families since the inception of its program. Among those using family selection, the population size of each family varied considerably, with the majority of producers creating families with more than 50 shrimp per family.

## POPULATION SIZE

The population size used to produce the next generation of broodstock is an important factor in domestication and selective-breeding programs, yet there seemed to be little concurrence on this parameter. A fourth of all participants initiated each new generation with as few as 1,000 animals, whereas another fourth used an initial population of 500,000 or more animals (Figure 7).

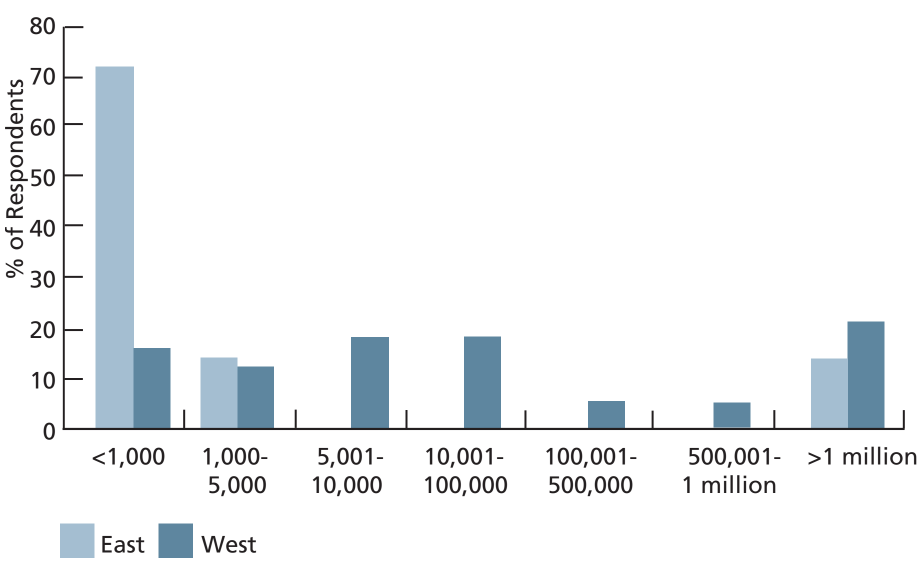


*Figure 7. Population sizes used in each generation.*

An effective population size is essential to avoid loss of genetic diversity through genetic drift. It is also recommended to evaluate the genetic diversity in current shrimp stocks to determine if it is sufficient to support domestication and selective breeding.

## INBREEDING RISKS

In addition to pathogen screening, the effectiveness of genetic improvement is influenced by the genetic diversity of the founder stocks. The results of the survey indicated that little attention has been given to this aspect of genetic improvement.

Many of the current breeding programs originated from small founder populations of only a few individuals. This strategy increases the risks of encountering inbreeding depression and can severely limit the potential for selective breeding.

Inbreeding is characterized by a loss of desirable traits and offspring viability, and a general decline in fitness. In 2001, Keys and coauthors demonstrated significant inbreeding depression in nauplii production within a single generation of deliberate inbreeding in *M. japonicus*.

Inbreeding depression can be minimized by maintaining large effective population sizes and avoiding recurrent selection for single gene traits and unintentional mating of siblings. Nearly 80% of the producers polled attempted to minimize inbreeding through management of their breeding programs.

Stated methods to prevent inbreeding were avoidance of full- or half-sib matings; tracing pedigrees before mating; crossing dual, parallel, unrelated populations; family crosses; and close monitoring of the increase in additive genetic relationships in the selected line using pedigree analyses.

The few responses that recommended a minimum number of generations of separation for safe breeding ranged from two to six generations. It should also be noted that under certain circumstances, inbred strains of shrimp can be beneficially exploited to produce heterozygote hybrids. However, the effects of inbreeding depression differ among species and traits.

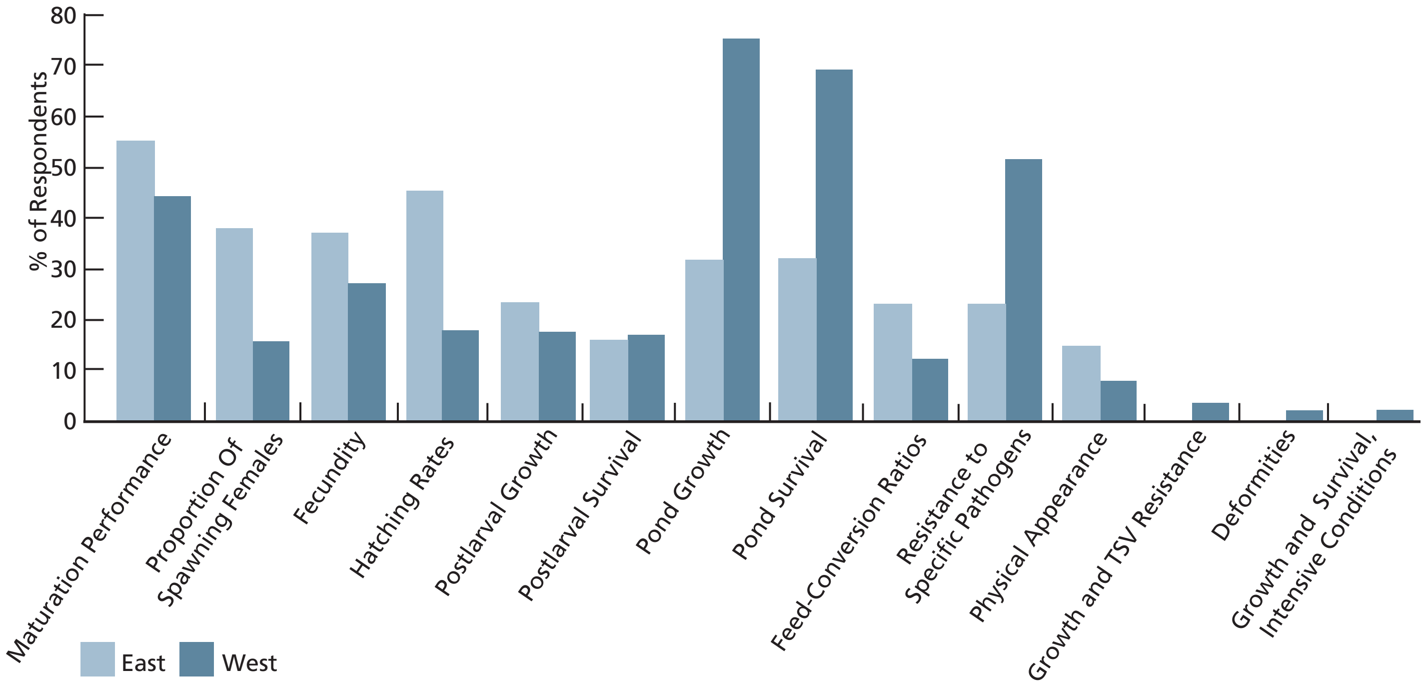


*Figure 8. Selection traits driving the genetic selection programs of survey participants.*

## SELECTION CRITERIA

The developmental stage in the shrimp life cycle at which selection criteria are scrutinized can play an important role in selective-breeding programs. Nearly a third of all respondents screened their animals for selected traits only when they attained adult size. Slightly more than half the producers began selecting for specific traits at juvenile and adult stages. It is also noteworthy that 13% of the participants screened for selected traits at larval, postlarval, juvenile, and adult stages of development.

The danger of prematurely culling individuals in a population at a larval or postlarval age based on specific traits associated with that developmental stage is that genes linked to other more desirable traits can be inadvertently purged. For example, larval shrimp that do not survive a rigorous hatchery-rearing protocol intentionally designed to maximize survival in larval tanks may represent the genotype possessing the fastest growth potential in ponds.

Selective factors in culture systems must be controlled to prevent indiscriminate selection from introducing bias into the process, resulting in inadvertent negative selection. All phenotypes must have an equal probability of being assessed for the traits of interest. Only those that do not possess the desired traits should be culled.

Producers can select for a large number of traits, including maturation performance, spawning rates, fecundity, hatching rates, PL growth, PL survival, pond growth, pond survival, feed conversion, resistance to specific pathogens, and certain morphological traits. The most common traits selected by the participants of the survey were growth and survival in ponds, and resistance to specific pathogens (Figure 8).

These traits were especially important to farmers, whereas reproductive and larval performances were more important to hatchery operators. Very few producers were concerned about improving feed conversion or selecting for specific morphological traits, although these criteria can also impact the economics of a culture operation.

Genetic improvement programs for other animals frequently assign breeding values to specific traits in order to quantify the selection processes. Only 14% of respondents stated that they assigned breeding values to specific traits, presumably due to lack of information regarding this methodology.

The survey questioned which analyses were utilized to quantify differences in selected traits among groups of shrimp and determine if measured improvements were statistically significant. The majority of respondents did not perform sophisticated statistical analyses of their performance data, but instead simply compared mean values between groups. Typical measurements were “growth to market size of 23 grams,” “average length,” “better average weekly growth,” “average survival in a specific pathogen challenge,” and “stress tolerance.”

More-sophisticated growers performed statistical analyses (T-test, ANOVA, general linear models, coefficient of variation, intrafamily variance) of their data. One advanced selective-breeding program evaluated genetic improvement using the Best Linear Unbiased Prediction Model. Another successful operation analyzed the results of their selective-breeding program using a methodology known as the Multiple Trait Derivative-Free Restricted Maximum Likelihood.

When selecting for multiple, unrelated traits, it is not uncommon to observe correlations between different traits. For example, it was reported in studies conducted at the Oceanic Institute that TSV resistance and growth were negatively correlated in certain selected families of *L. vannamei.* Of the survey participants who selected for multiple traits in their breeding programs, 36% reported correlations between two selected traits.

*Survey respondents reported varied gains in growth and disease resistance due to their genetic improvement programs.*

Based on the results of a selective-breeding plan, one of the participants noted an "unfavorable genetic relationship between growth and WSSV resistance" and a "consistent positive correlation between growth and pond survival in a WSSV-free environment." If important traits are negatively correlated and appear to be genetically linked, then establishing two separate lines, each selected for one of the traits, could provide a viable solution.

## GENETIC GAINS

The measure of success of a selective-breeding program is the degree of improvement in the desired traits. In one 1999 study with salmonids, Gjedrem reported genetic gains of 10 to 12% per generation in response to selection for growth rate. He suggested that a reasonable goal for selective-breeding programs should be genetic gains of 10 to 15% per generation for growth, or 10% per generation when selecting for disease resistance.

Survey responses rating genetic gains were highly variable. One producer attempting to select for WSSV tolerance and growth in *L. vannamei* observed a one-generation survival increase from 10% to 25% in response to the first selection process for WSSV resistance in the F1 generation, which subsequently increased to 35% survival following another selective screening imposed on the F2 generation. The same grower was not able to quantify improvements in growth due to extraneous factors, which confounded interpretation of the results.

Another respondent reported multitrait selection gains of 5 to 12% per generation, despite unfavorable genetic relationships between traits. Other individual reports of quantifiable genetic gains from the survey participants are reported in Table 2.

One participant reported a substantial increase in low-oxygen tolerance in the shrimp in his selective-breeding program, although it was unclear what methods were used. Several participants said they developed domesticated lines of broodstock that did not require eyestalk ablation to stimulate ovarian development.

## SPR STOCKS

Many of the survey participants utilized breeding programs to produce SPR shrimp for their own production needs or sale to third parties. Seventy-three percent of them screened their SPR broodstock to confirm they were free of notifiable pathogens. Polymerase chain reaction (PCR) and commercial test kits were the preferred diagnostic methods for confirming the disease-free status of SPR broodstock.

Nearly two-thirds of the same group stated they used specific pathogen challenge bioassays to confirm the SPR status of their selected shrimp. The most common pathogens for which they attempted to breed resistance were WSSV and TSV, and to a lesser extent YHV and IHHNV.

## PROTECTION OF PROPRIETORY LINES

Based on the responses to the survey, it was clear that growers who possessed proprietary lines of domesticated shrimp took few precautions to avoid unauthorized use of their animals. The lack of proven, practical techniques is probably the main reason behind this failure.

*Table 2. Representative gains and benefits from genetic improvement programs reported by survey participants.*

| Improvement in Growth | Resistance to TSV | Resistance to IHHNV | Resistance to WSSV |
|---|---|---|---|
| 10% increase per generation, 20% (absolute) in four generations<br>Increase 0-5% per generation, 30% (absolute) in 10 years<br>20% (absolute) in five years<br>25% (absolute) during the genetic improvement program 90% (absolute) for five years | 5-12% (absolute) survival increase per generation<br>20% survival increase in one generation 32% (absolute) total in three years<br>300% survival increase for three years<br>90% (absolute) for five years | Average survival increased from 10% to 90% in eight years | Survival<br>• 10% (FO)<br>• 25% (F1)<br>• 35% (F2) |

Only two producers stated they intentionally inbred or sterilized their shrimp lines as a deterrent to piracy.

## RESEARCH PRIORITIES

When ranking research priorities for genetic improvement, survey participants placed the most attention on improving rates of genetic improvement, preventing disease contamination, increasing the number of selected lines or traits, and methods to prevent unauthorized use of domesticated lines. Additional priorities included further development of disease-resistant lines of shrimp, improved growth rates and growth uniformity, biosecurity, gamete cryopreservation, microsatellite analysis of genetic variability, and development of shrimp strains selected for tolerance to specific environmental conditions.

## SUMMARY

In the Western Hemisphere, the domestication and selective breeding of the dominant farmed species (*L. vannamei* and *L. stylirostris*) have become widespread practices with clearly demonstrated benefits. The benefits include a more reliable supply of seedstock and improved production efficiency resulting from the selection of genotypes with faster growth rates or improved tolerance to disease. Domesticated lines of white shrimp have been reared in captivity for more than 30 generations.

Despite the potential benefits, the domestication and selective breeding of the dominant farmed species (*P. monodon*) has been remarkably slow in the Eastern Hemisphere, but is now moving ahead. However, considerable progress has been made in the domestication and selective breeding of species that are less commonly farmed in the East, including native species such as *M. japonicus, P. merguiensis*, and *P. chinensis*, and, most significantly, species introduced from the West, particularly *L. vannamei* and *L. stylirostris*.

The results of the survey suggested that the rate at which the global shrimp-farming industry is able to progress from reliance on wild stocks to the use of domesticated, selectively bred stocks will be a major determinant of sustainability and profitability. The survey also revealed key factors that determine the success of shrimp domestication and selective-breeding programs, irrespective of the target species.

An improved understanding of these factors, gained from experience with individual species, should facilitate the global rate of progress among all farmed species. For shrimp like *P. monodon* still in the early phases of domestication, the results of the survey provided useful insights on ways to improve the efficiency and effectiveness of the task ahead.

Although shrimp culturists have made significant advances in domestication, selective breeding, and stock improvement in recent years, GAA's OP survey highlighted the relatively slow progress of domestication and selective breeding in the Eastern Hemisphere. In many Eastern farming regions, belated attempts to achieve domestication and selective breeding of native species are now hampered by the high incidence of viral pathogens. In response to these circumstances, the industry has dramatically expanded the use of species introduced from the West, particularly *L. vannamei*, to take advantage of the many generations of successful selection of this species.

The results of the GAA survey indicated that techniques for screening founder stocks for viral pathogens and rearing broodstock under biosecure conditions will be critical to continued successful domestication. The survey also showed that SPR lines of shrimp capable of tolerating IHHNV and TSV are currently available in the Americas, and progress is being achieved in the development of WSSV-tolerant lines of shrimp.

Technologically advanced growers have embraced multifamily selection, hybrid crosses, and genetic markers as important tools for developing faster-growing, disease-resistant shrimp. The rest of the industry should follow their lead.

*The rearing of broodstock under biosecure conditions and diligent screening for diseases are critical factors for successful domestication.*

## Recommendations

- Utilize multiple founder populations with as large a genetic diversity as possible to establish genetic improvement programs.
- Using the most sensitive diagnostic tools available, screen founder populations for pathogens to assure they are free of disease.
- Maintain and procreate breeding stocks in biosecure nucleus-breeding centers to preserve SPF status.
- To maximize the rate of genetic gains while maintaining SPF status, family selection strategies should be favored over mass selection. Mass selection can be used to build disease-resistant populations in areas where biosecurity measures and disease exclusion are not viable options.
- Within a family selection program, the largest number of families per generation or breeding session should be used to direct genetic improvement programs.
- Controlled laboratory challenges are recommended as a means of selecting for disease resistance and creating SPR lines of shrimp. The findings of laboratory challenges can be validated in field trial challenges.
- SPF and SPR strategies are not mutually exclusive and should ideally be combined simultaneously in any genetic improvement program striving to develop disease-resistant lines of shrimp.
- Practice high selection pressure within regions, and allow favorable, controlled gene flow between regions.
- As the knowledge base of the shrimp genome expands, molecular marker-assisted selection techniques may some day replace family selection strategies.
- International cooperation in disease and genetics should be encouraged in order to better understand underlying processes.

## For Additional Information


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# HATCHERY

## *Maturation*

GLOBAL AQUACULTURE ALLIANCE

# Maturation

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## Principles

A significant global trend in shrimp production is a shift from the use of wild spawners to domesticated, high-health, genetically improved stocks. This trend, while more prevalent in the Western Hemisphere, is becoming a driving force in the approaches to and management of maturation systems worldwide.

The use of wild broodstock is risky because they can be carriers of pathogens, and farmers who routinely use wild broodstock as spawners are unable to benefit from genetic improvement. As the economic benefits of biosecurity and genetic improvement become more compelling, it is likely the global shrimp-farming industry will invest in selective-breeding programs that rely on high-health or specific pathogen-free (SPF) stocks. This paradigm shift will require improved methods for captive reproduction that include innovative maturation technologies.

## Survey

In the context of this survey, maturation was defined as the processes and techniques used to maintain and condition broodstock in order to stimulate gonadal development and spawning, and assess spawning performance.

Forty-eight respondents answered the maturation-related questions. Thirty-four of the respondents were from countries in the Western Hemisphere (West), and 14 were from the Eastern Hemisphere (East).

*Once raised almost exclusively in the Western Hemisphere,* L. vannamei *are increasingly cultured in the East. Note the attached spermatophore on this mature shrimp. Such open-thelycum species mate immediately before spawning.*

### CULTURE SPECIES

There was a clear difference between the two hemispheres with regard to the dominant penaeid shrimp species cultured (Figure 1). About 95% of the Western respondents (representing Belize, Brazil, Colombia, Dominican Republic, Ecuador, Honduras, Mexico, Panama, United States, and Venezuela) said they raised Pacific white shrimp, *Litopenaeus vannamei*. In the East (India, Madagascar, Saudi Arabia, and Australia), 86% of the respondents grew black tiger prawns, *Penaeus monodon*.

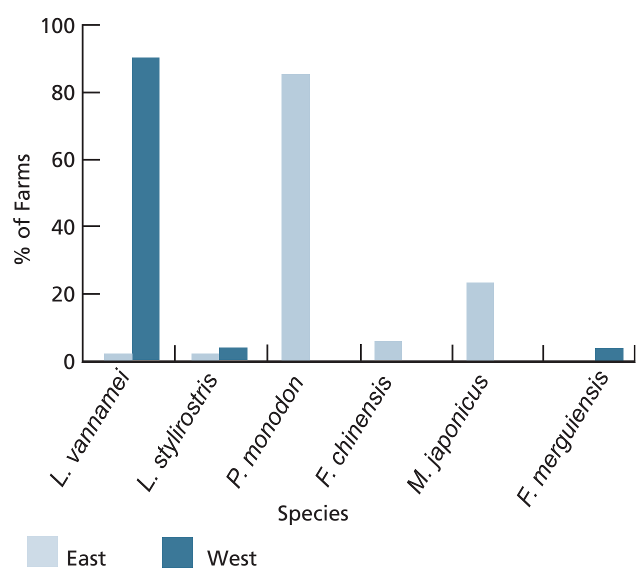



*Figure 1. Species grown in the Eastern and Western Hemispheres.*

Taiwan was the only Eastern country represented in the survey that cultured *L. vannamei*. However, since the survey was conducted in 2001, *L. vannamei* have been widely introduced in China, Thailand, Vietnam, and other shrimp-producing countries in the East.

Some respondents also grew other penaeid species, including *L. stylirostris* (three respondents), *Fennero-penaeus merguiensis* (three), *F. chinensis* (two), and *Marsupenaeus japonicus* (one respondent).

*Black tiger shrimp,* P. monodon*, are a closed-thelycum species in which mating occurs immediately after molting of the female. The spermatophore is inserted into the thelycum, where the sperm remain viable for days or weeks in advance of spawning.*

## BROODSTOCK

The benefits of using domesticated broodstock were more recognized in the West than the East (Figure 2). The dominance of domesticated broodstock in the West, principally *L. vannamei*, developed over the past decade in response to disease management needs and the recognition of potential efficiencies from genetic improvement. The emergence of genetically improved, SPF stocks provided greater control over production, greater efficiency, and higher predictability of both stocking and harvest outcomes.

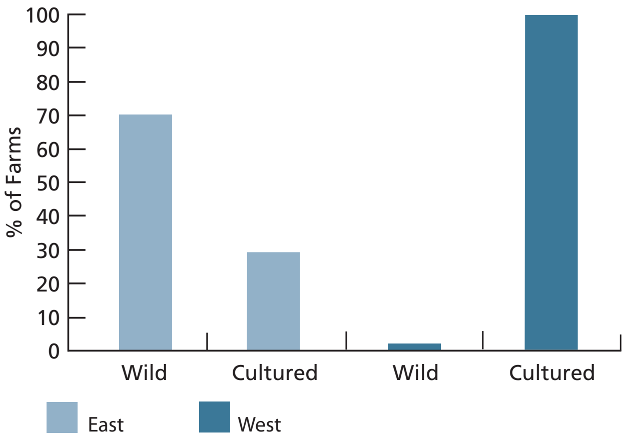



*Figure 2. Sources of shrimp broodstock in East and West.*

*P. monodon* raised in the East have been less amenable to domestication, hence the common use of wild broodstock in the region. A critical issue for the sustainability of *P. monodon* production there is the development of domesticated broodstock with reliable and predictable reproductive performance.

Several research efforts currently are directed toward this challenge, with some success seen on the research scale. There is a reasonable expectation that the development of domesticated lines on an industrial scale will take place in the next few years.

Domesticated *M. japonicus* and *F. merguiensis* stocks make up only 29% of the broodstock used in the East. There is an urgent need to develop genetic improvement programs and SPF stocks for all cultured penaeid shrimp species.

P. japonicus *is a closed-thelycum species.*

## MATURATION FACILITIES

A significant trend in the survey was the increasing level of technology and industrialization of maturation facilities. Maturation facilities typically are in the second or third generation of development, resulting in highly specialized facilities capable of the consistent production and maturation of large numbers of broodstock. Strict environmental controls, rigorous biosecurity approaches, and automated monitoring systems are important features of several state-of-the-art facilities

Over 40% of the Eastern maturation facilities had between five and 20 maturation tanks, whereas facilities in the West tended to be larger. A significant number of facilities in the West had over 20 maturation tanks (Figure 3).

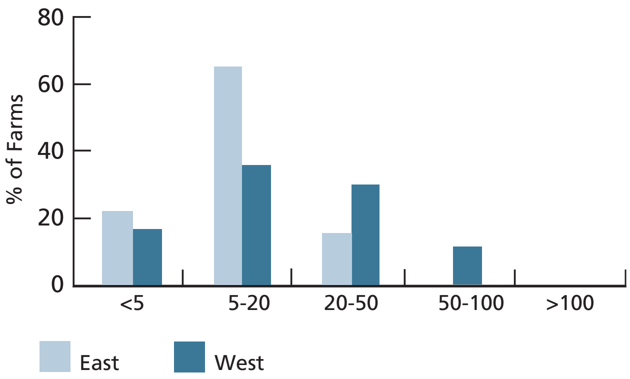



*Figure 3. Numbers of maturation tanks used in maturation facilities.*

Concrete maturation tanks were most common in the East (64% of respondents), followed by fiberglass (30%), and plastic-lined tanks (7%). In contrast, 66% of Western respondents used plastic-lined tanks, followed by fiberglass (15%), and concrete (15%) tanks.

The configuration of maturation tanks varied substantially between the East and West (Figure 4). Round tanks were most common in the West (81% of respondents), whereas 62% of the Eastern respondents used round tanks along with square and rectangular tanks. Maturation tank volume typically was 5 to 20 cubic meters (72% in the East, 78% in the West).

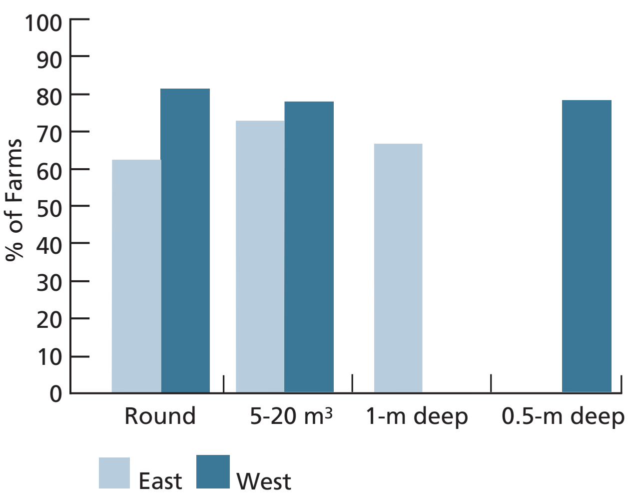
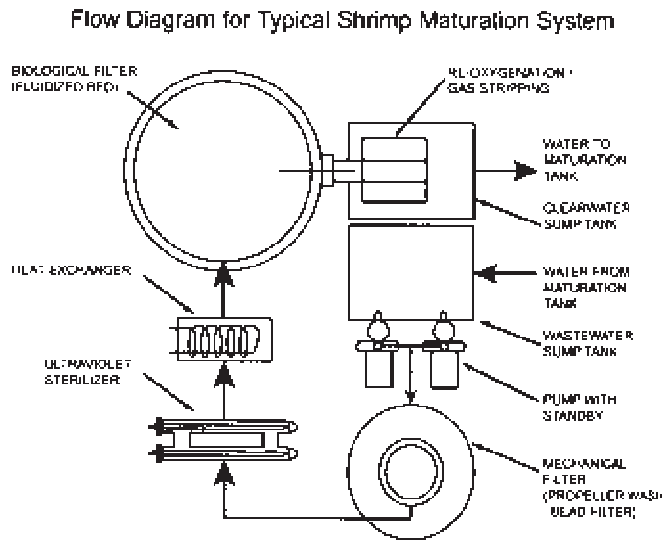



*Figure 4. Common configurations of maturation tanks in the Eastern and Western Hemispheres.*

A major contrast between hemispheres was tank depth, where 67% of Eastern respondents used tanks about 1 meter deep, and 78% of Western respondents used tanks of 0.5 meter depth or less. This was likely a consequence of the different shrimp species cultured.




*Schematic diagram of a recirculating system for maturation. Diagram courtesy of Aquaneering.*

*Maturation tanks are typically round in shape and black in color.*

## TANK MANAGEMENT

As management practices of maturation facilities evolve, the strategy of flow-through water exchange is progressively giving way to recirculating or partially recirculating systems, particularly in the West. Recirculating systems provide advantages for biosecurity, water quality control, and potential savings in heating and pumping costs.

At the time of this survey, only 18% of the Eastern respondents used recirculating systems, in contrast to 54% of the Western respondents. For respondents who recirculated water, the most common types of biofilters were fluidized-bed filters (33%) and pressurized-sand filters (33%). Filtration of incoming water was common in both the East and West, with pressurized-sand filters (22%) and cartridge filters (19%) the most common filter types.

*Fluidized-bed biofilter installed in a shrimp maturation system. Photo courtesy of Aquaneering.*

Daily water exchange rates were lower in the West, possibly due to the more frequent use of recirculating systems. Water exchange rates typically ranged from 50 to 150% per day (52% of respondents), although 20% used higher exchanges of 150 to 200% per day.

The use of substrates in maturation tanks is a relatively recent innovation applied principally in the East, where *P. monodon* is the dominant species. The benefits of substrates are more aligned with the natural behavior of the species than with *L. vannamei*.

The potential benefits of sand or gravel substrates in maturation tanks include stress reduction by providing shelter and allowing natural burying behavior, improved water quality, and improved reproductive performance of broodstock. However, only 17% of the Eastern respondents claimed to use substrates. Only 3% of Western respondents used them.

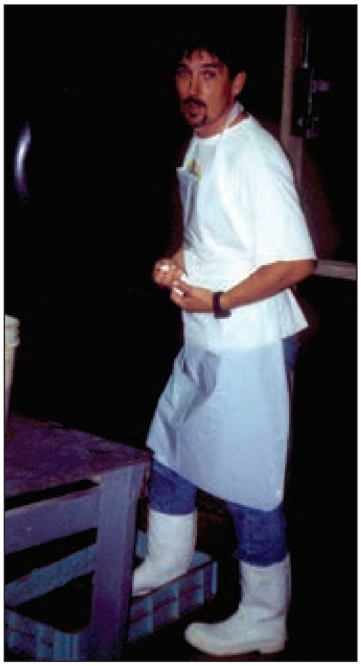
*Sand substrates are not required for the captive maturation of* L. vannamei.

## BIOSECURITY

Over the past decade, attention to biosecurity issues in maturation facilities has become critical to the successful management and performance of stocks. In response to outbreaks of virulent shrimp pathogens throughout the major shrimp-farming regions of the world, the industry developed SPF stocks.

The concomitant need to monitor and preserve SPF status in broodstock facilities is the first step for disease management in the overall production environment. Viral-screening protocols, quarantine protocols, disinfection of incoming water, feed irradiation, worker sanitation protocols, and the use of saline groundwater are additional components in the improvement of biosecurity in maturation facilities.

*Sanitation procedures like apron use and foot baths are important for health management in maturation facilities. Photo courtesy of Harlingen Shrimp Farms.*



Viral screening of stocks for White Spot Syndrome Virus (WSSV), Taura Syndrome Virus (TSV), Infectious Hypodermal and Hematopoietic Necrosis Virus (IHHNV), and Yellow Head Virus is prevalent in the West, whereas WSSV, TSV, IHHNV, Monodon Baculovirus, and Gill-Associated Virus are commonly checked in the East (Figure 5). Only 7% of Western respondents and 11% of Eastern respondents did not screen broodstock and/or larvae for viruses.

It is common for maturation facilities and hatcheries to have on-site polymerase chain reaction laboratories for viral screening. Continued attention to biosecurity issues will likely remain critical for the successful operation of maturation facilities.

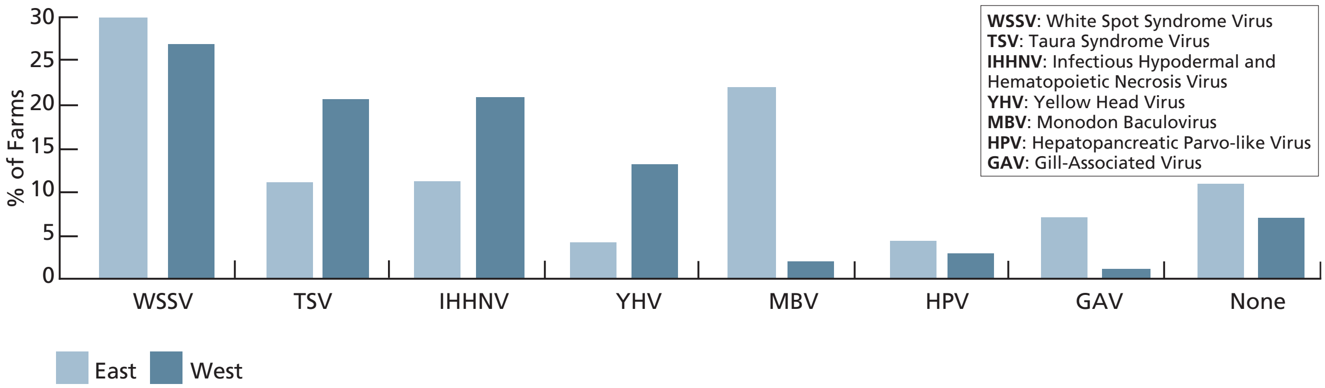



*Figure 5. Viruses screened by East and West respondents.*

## MATURATION

Stocking densities in maturation tanks were lower in the East, possibly as a consequence of the shrimp species cultured. Most (62%) Eastern respondents stocked two to five broodstock per cubic meter of water, predominantly using *P. monodon*. In the West, most (87%) respondents stocked six or more *L. vannamei* broodstock per cubic meter. In the East, the most common female:male ratios were 1:1.5 (25%) and 1.5:2 (25%). In the West, the most common (59%) strategy was to stock equal numbers of females and males.

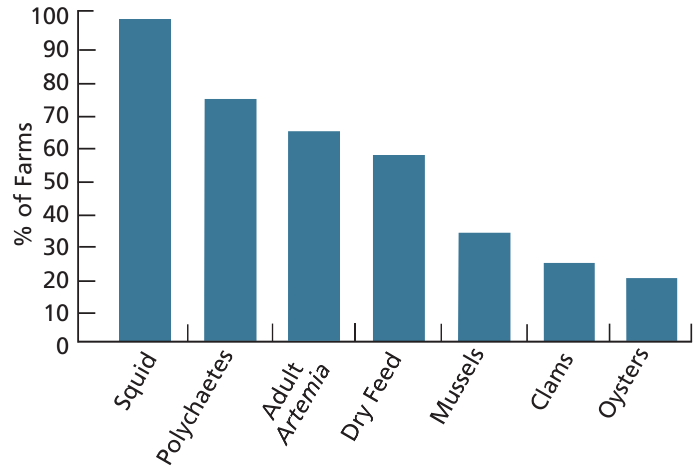
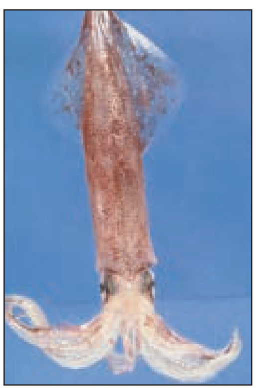



*Figure 6. Common ingredients used in maturation diets for commercially important penaeid shrimp.*



*Typical natural food supplements offered to maturing shrimp include squid (left) and polychaete worms. Worm photo courtesy of Seabait, Ltd.*

Proper feeds and feed management are essential to maintain healthy broodstock and stimulate gonadal development. The most common (86%) item used in maturation diets was squid (Figure 6). Polychaetes (66%), adult *Artemia* (57%), and dry feeds (49%) also were important dietary components. Bivalves such as mussels (29%), clams (20%), and oysters (17%) were used less frequently.

Maturation diets containing ingredients of marine animal origin must be used with caution because these items can serve as vectors for disease. Interestingly, only 5% of respondents in the West irradiated their feeds, whereas none of the respondents in the East reported this.

Most (67%) respondents from the East fed broodstock to satiation, whereas 64% of the Western respondents determined feeding rates based on shrimp body weight. About half the respondents in the East and West fed broodstock four times per day, although a significant percentage (38%) of Western respondents reported feeding broodstock five or more times daily.

To ensure adequate gonadal development, Eastern respondents reported that broodstock typically were held two to five days in maturation tanks prior to the induction of spawning. In contrast, Western respondents indicated broodstock were typically held six to 20 days – a difference that likely reflected the varied requirements of *P. monodon* and *L. vannamei*.

After an initial preconditioning period, ovarian development was assessed visually, although the most common method to accomplish the assessment differed between hemispheres. Most (76%) respondents in the East reported visual inspection of female broodstock using an underwater light to candle the ovary. In contrast, 88% of the Western respondents reported they visually inspected female broodstock above the water using a flashlight.

Respondents induced spawning a number of ways, including eyestalk ablation; manipulation of temperature, photoperiod, and salinity; and the use of dietary additives (Figure 7). Eyestalk ablation, the preferred method in both hemispheres, typically was accomplished on all females, irrespective of whether they had ripe ovaries or were in post-molt.

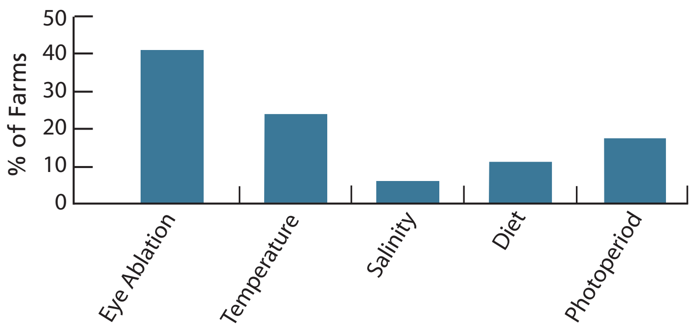



*Figure 7. Methods used to induce spawning of shrimp.*

The most common ablation techniques differed between hemispheres. Cauterization with a hot iron dominated (57%) in the East, and cutting with a blade dominated (53%) in the West.

*Eyestalk-ablated female with numbered band attached to intact eyestalk to monitor reproductive performance.*

Irrespective of hemisphere, natural mating in the maturation tanks was the most common mating system used. Over 90% of the respondents indicated they used natural mating, while about 9% used artificial insemination. Artificial insemination was typically performed when it was important to identify parents, such as in a selective-breeding program. Once females were inseminated, they typically were removed from the maturation tanks.

In the East, 60% of the respondents stocked one female in a single spawning tank, whereas in the West, 69% o fthe respondents stocked multiple females in a single spawning tank. Only 4% of the respondents indicated that bulk spawning occurred in the maturation tanks.

## PERFORMANCE

The differences in spawning performance between hemispheres likely reflected the physiological and/or behavioral differences between *P. monodon* and *L. vannamei*, as well as differences in our understanding of the reproductive biology and captive rearing of these two species.

For example, Eastern respondents reported variable nightly spawning ranging from 5% to greater than 12%. In contrast, 42% of the Western respondents reported 7 to 8% of females spawning. In addition, there were differences in the number of spawns achieved by each female.

In the East, 75% of respondents reported that each female spawned two to five times. In the West, 45% of respondents reported that each female spawned six to 10 times, and 31% of respondents reported that each female spawned more than 10 times.

Significant differences in shrimp performance between hemispheres and species were reflected in the number of eggs produced per female (Figure 8). In the West, 90% of females produced less than 200,000 eggs per spawn – typical for *L. vannamei*. In contrast, in the East, 75% of the females produced more than 200,000 eggs per spawn, which was typical for *P. monodon*. Hatching rates also varied. In the East, 40% of respondents reported hatching rates of 50 to 60%, whereas in the West, 50% of respondents reported hatching rates of 71 to 80%.

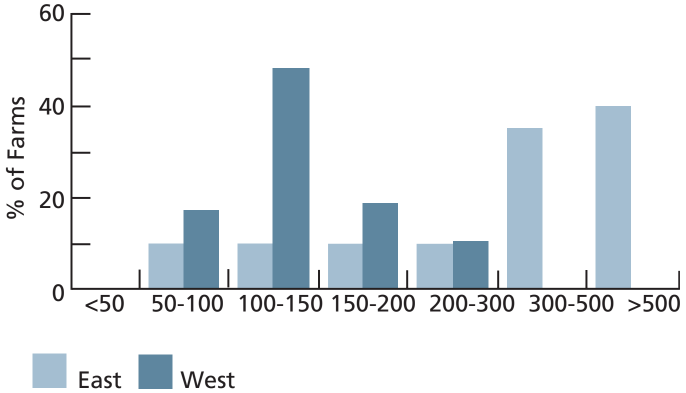



*Figure 8. Reported number of eggs per spawn (x 1,000) for shrimp broodstock in the East and West.*

With regard to survival of shrimp from nauplii to 15-day postlarvae, 60% of the respondents in the East reported survivals ranging from less than 30% to 50%. In contrast, 67% of respondents in the West reported survivals ranging from 51% to greater than 70%. Again, these collective differences likely were the result of inherent biological differences between the two dominant species in the East and West.

For those respondents who used both wild and domesticated broodstock, the majority indicated that domesticated shrimp were easier to handle and/or showed less fright response than wild shrimp, irrespective of hemisphere. However, 73% of the respondents from the East claimed that wild shrimp had better survival in maturation tanks, higher spawning rates, and more spawns per female. About 89% said the wild animals provided more eggs per spawn, while 54% said they exhibited a higher hatching rate than domesticated shrimp.

In contrast, all respondents from the West claimed that domesticated shrimp had better survival in maturation tanks, 79% claimed higher spawning rates, 57% reported more eggs per spawn, 92% indicated more spawns per female, and 79% claimed a higher hatching rate than wild shrimp.

*Eastern respondents reported that wild shrimp delivered better reproductive performance than captive animals, while Western respondents reported the reverse.*

As mentioned previously, despite the perception in the East that wild shrimp perform better than domesticated shrimp, there are compelling biosecurity, environmental, and economic reasons to domesticate all commercially important penaeid shrimp species with the ultimate goal of producing SPF, genetically improved stocks for the industry.

## FUTURE RESEARCH

Although tremendous advances have occurred over the past decade with regard to maturation technology, a number of areas require further research. In identifying the top research priority areas for improvements in maturation performance, respondents in the East keyed on broodstock growout and preconditioning (54%), hormonal manipulation (23%), diet (15%), and spawning systems (8%). Western respondents indicated diet (45%), broodstock growout and preconditioning (34%), spawning systems (10%), and other areas (10%) as areas for improvement.

In light of disease problems within the global shrimp-farming industry, there have been fundamental changes in the way broodstock managers operate their maturation facilities. The use of domesticated stocks from SPF sources has increased, and biosecure protocols are now common.

In a maturation survey conducted by David Kawahigashi in 1992, 80% of the broodstock used by shrimp farmers in the West were from the wild. In contrast, GAA's survey indicated that about 97% of respondents from the West used broodstock from captive populations, and there appears to be an increasing trend in the East to use captive stocks.

In a 1998 survey, Kawahigashi reported that only four of 34 respondents used water recirculation technology at their facilities. Several years later, this survey reported that 56% of the respondents depended on partial or complete water recirculation. It appears that technologies to enhance biosecurity will continue to be adopted by broodstock managers with the expectation that they will increase production and profitability.

*Pond-reared* P. monodon *broodstock.*

# Recommendations

In order to ensure a predictable supply of high-quality postlarvae to the growing shrimp-farming industry, hatchery managers must adopt rigorous biosecurity protocols that include the use of SPF shrimp, adequate water filtration processes, and proper disinfection protocols. In addition, the use of domesticated stocks must become a routine practice.

Domesticated stocks can be protected from pathogens more easily than wild stocks and used in genetic improvement programs to enhance commercially important traits such as growth and disease resistance. By adopting rigorous biosecurity protocols and taking advantage of genetic selection, the global shrimp-farming industry will be in a better position to supply high-quality products to the growing market.

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# HATCHERY

## *Larval Rearing*

GLOBAL AQUACULTURE ALLIANCE

# Larval Rearing

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## Principles

In the early years of shrimp farming, producers relied mainly on wild-caught postlarvae for stocking ponds. In many areas, supplies of wild postlarvae were not dependable, so hatchery techniques for spawning wild-caught broodstock were developed. This practice is still used widely, but the availability of wild broodstock has declined in some areas, and the animals may be infected with diseases. Thus, the present trend is toward using broodstock to produce hatchery postlarvae.

A major goal of the shrimp industry should be to eliminate dependence on wild shrimp stocks as soon as possible. This would greatly enhance environmental responsibility and provide better assurance of disease-free, high-quality postlarvae for growout ponds.

Hatcheries vary greatly in size from small "back yard" operations to large, industrial-style facilities capable of producing millions of postlarvae per month. There is an equally wide variation in hatchery types.

Some hatchery practices are more environmentally responsible, efficient, and effective in controlling diseases than others, and these practices should be encouraged. Some examples of good practices are the use of domesticated broodstock, reduction in *Artemia* use, adoption of biosecurity measures, restricted use of antibiotics and other therapeutants, evaluation of larval quality, effluent treatment, and prevention of shrimp escapes into surrounding waters.

The shrimp-farming industry cannot be considered a mature industry until hatcheries rely entirely upon domesticated broodstock and consistently provide high-quality postlarvae. In addition, those involved in shrimp growout cannot claim to provide environmentally and socially responsible products unless their postlarvae are obtained from hatcheries that apply responsible procedures. Shrimp hatcheries are a critical link in the chain for supplying consumers with quality shrimp produced by responsible aquaculture practices.

*The practice of using wild spawners like this* Penaeus monodon *is steadily giving way to the use of domesticated broodstock.*

## Survey

The Global Shrimp OP Survey sought data on the main features and operating procedures of shrimp hatcheries. Responses were obtained from 79 hatcheries located in 20 countries. One hatchery in Mozambique and three hatcheries in Australia were included in the Eastern Hemisphere component.

The breakdown by country showed that United States hatcheries were overrepresented in the West, possibly because of greater Internet awareness and survey completion by even small and research-oriented hatcheries. Although the breakdown of respondents in the East revealed the absence of entries from China and a low number of respondents from Thailand, the survey results presented a reasonable picture of shrimp hatcheries that showed the physical nature and practices of hatcheries are quite different in the Eastern and Western Hemispheres.

A review of the distribution of responses suggested the survey was biased toward well-established hatcheries. Clearly, the majority of hatcheries in the West were well established – 72% of the respondents reported operations over six years or more. A similar picture was observed in the East, with 60% of facilities operating for at least six years. This situation could be considered a handicap, but tends to reflect the latest trends and techniques of the industry's leaders.

*Hatcheries vary from small back yard affairs with simple outdoor concrete tanks to large-scale commercial facilities.*

## BROODSTOCK, NAUPLII

In the West, most hatcheries have discontinued the use of wild shrimp for broodstock in response to the viral disease problems of the last 10 years. Only one hatchery reported reliance on wild broodstock. This marks a radical change, as just a few years ago, hatchery-reared postlarvae were commonly regarded as inferior to their wild counterparts.

In contrast, hatcheries in the East still relied heavily on wild spawners. About 17% of the hatcheries reported raising immature wild adults into broodstock. The number of hatcheries reporting the use of shrimp from breeding programs (11% of respondents) was not typical of Asia, where few hatcheries have access to such stocks. Ten percent of respondents later said they raised animals that had been modified by selective breeding.

Only 8% of respondents reported they did not spawn shrimp in house, but purchased nauplii from independent producers. In reality, the percentage of such larval-rearing facilities in Asia is much higher than the survey suggested and far greater than the number of hatcheries that use nauplii from breeding programs.

## CAPACITY, INTEGRATION

The majority of responding hatcheries in the Americas were of medium size, reporting capacities between 11 million and 50 million postlarvae per month. In the East, the modal rate of hatchery production was much lower. Almost half the hatcheries in the East reported production between one million and five million postlarvae per month. However, the survey indicated that larger hatcheries producing six million to 50 million postlarvae per month are becoming more common. The survey also included an Indonesian "megahatchery" with a monthly production capacity exceeding 200 million postlarvae.

To identify the degree of integration of their production systems, hatcheries were asked whether their operations included growout farms. Integration with farms was reported by 82% and 65% of the respondents in the West and East, respectively. These numbers suggested a larger proportion of integration than would be typical for both regions.

## SPECIES

As expected, the great majority (92%) of Western hatcheries reported working with Pacific white shrimp, *Litopenaeus vannamei*. Only one hatchery raised Pacific blue shrimp, *L. stylirostris*, reflecting loss of interest in the previously popular species.

In Asia, 89.5% of the respondents reported working with *P. monodon*. Only one worked with *L. vannamei* – a reflection of the lack of input from China and Taiwan (which may also explain the absence of *Fenneropenaeus chinensis*), and the timing of the survey, which closed before the introduction of this species into many other hatcheries in the region. *M. japonicus* were produced by two respondents.

## HATCHERY TANKS

The modal number of larval-rearing tanks (31 to 50) was higher in the West than the East (11 to 20). Although these categories probably represented the majority of hatcheries, the proportion of facilities with more than 50 larval tanks was likely less than that suggested by the survey.

Modal tank volumes for hatcheries in the West were 11 to 15 tons. In the East, volumes were in the five- to 10-ton range. The full five- to 50-ton range was well represented in both hemispheres.

*According to the survey, smaller tanks like the 10-cubic-meter fiberglass units above are gaining popularity over large rectangular concrete tanks.*

The most striking feature in the East was the increasing trend toward smaller tanks, with over 36% of respondents using tanks smaller than 10 tons and over 75% using tanks of less than 20 tons capacity. This was quite different from the situation 10 to 15 years ago, when the predominance of "Taiwanese-style" systems with tanks of greater than 30 tons capacity was clear. This observation may be partially explained by the absence of significant respondents from China, Taiwan, and Japan, where larger tanks are still popular.

## WATER TREATMENT

The most common methods for water disinfection in both hemispheres were chlorination (42% and 47% of the West and East hatcheries, respectively), ultraviolet irradiation (42%, 47%), and ozonation (14%, 12%). Some hatcheries used combinations of these methods.

Only half the respondents reported the bacterial load reduction expected by the water treatment regime. This illustrated the general lack of concern or knowledge about bacterial loads. The majority of the respondents who counted bacteria in incoming water reported a reduction of 99.0 to 99.9% of the bacterial load after disinfection treatment.

*Modern hatcheries maintain a sanitary culture environment. Photo courtesy of National Prawn Co., Saudi Arabia.*

## WATER DISCHARGES

By industrial or agricultural standards, shrimp hatchery discharges are minimal in volume, with even the largest facilities rarely exceeding 2,000 metric tons daily. Recirculation systems, common in the broodstock production and maturation components of hatcheries, further minimize discharges.

The most typical range of water volume discharged by hatcheries in both hemispheres was 50 to 500 metric tons per day. The tendency for a greater proportion of small hatcheries was reflected by 33% of the Eastern hatcheries discharging less than 50 metric tons daily, as compared to 20% of Western hatcheries in this range.

The treatment of hatchery discharges is a growing concern because of increased environmental awareness and regulations. Treatment often is geared toward animal containment and health management, including the prevention of intake and discharge water mixing. The use of varied discharge treatments is presented in Table 1.

*Table 1. Methods of discharge treatment utilized in the Eastern and Western Hemispheres.*

| Water Discharge Method | Eastern Hemisphere | Western Hemisphere |
|---|---|---|
| Oxidation and sedimentation ponds | 35% | 38% |
| Infiltration/percolation ponds | 17% | 14% |
| Mechanical filtration | 7% | 20% |
| Discharge into a mangrove area | 10% | 8% |
| Injection wells | 10% | 4% |
| Disinfection/sterilization | 7% | 8% |
| Do not treat discharges | 14% | 8% |

It was interesting to note that mechanical filtration was three times more popular in the West than the East. Injection wells were not very popular in either hemisphere, but showed a greater prevalence in the East. The remaining methods did not show significant differences in popularity between the two hemispheres.

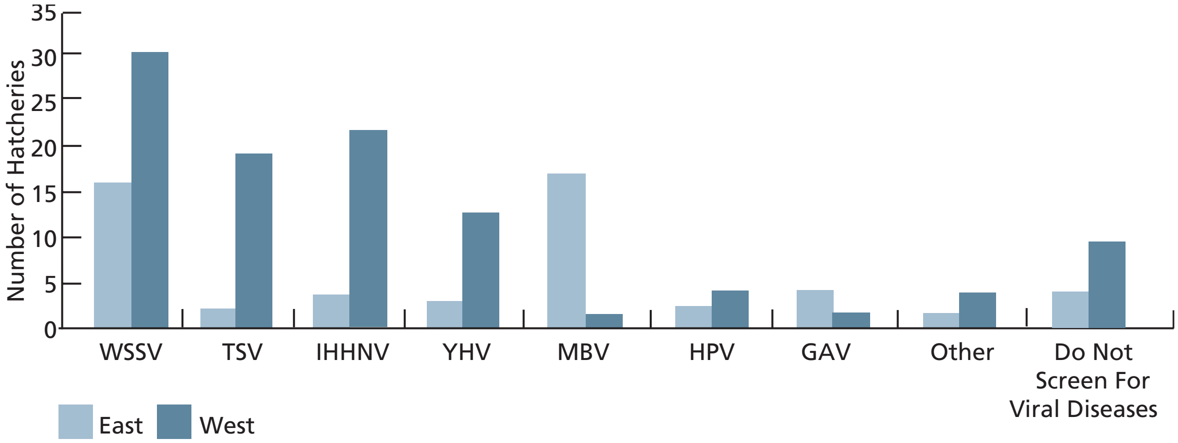



*Figure 1. Diseases for which hatcheries screened.*

Environmental authorities increasingly require monitoring of the chemical make-up of discharges. The most commonly monitored variables in hatcheries of both hemispheres were total suspended solids, total phosphorus, total nitrogen, and biological oxygen demand. Results showed 10 to 19% of the hatcheries monitored each of these parameters, while roughly one-third of the respondents reported no monitoring.

## DISEASE MANAGEMENT

A series of survey questions aimed to identify management procedures throughout the production cycle. The first question covered viral disease screening of broodstock, nauplii, larvae, or postlarvae (Figure 1).

As might be expected, Western hatcheries were more concerned with White Spot Syndrome Virus (WSSV), Infectious Hypodermal and Hematopoyetic Necrosis Virus (IHHNV), and Taura Syndrome Virus (TSV). The main viruses of concern to Eastern hatcheries were WSSV and Monodon Baculovirus (MBV), and most respondents screened for both. Other viruses were of limited interest, suggesting that even some of the hatcheries using domesticated broodstock were not greatly concerned about diseases other than MBV and WSSV.

## NAUPLII TREATMENT

Another practice investigated by the survey was the rinsing and disinfecting of nauplii. Good management practices, such as rinsing nauplii through several molts with abundant clean water and disinfecting them with iodophore compounds, can be very effective at reducing bacterial problems and minimizing the horizontal transmission of pathogens. The most common nauplii treatments are presented in Figure 2.

Rinsing nauplii with clean sea water was the most common method, followed by disinfection with iodophore compounds. The use of antibiotics in nauplii was reported by a significantly higher percentage (23%) of Eastern than Western hatcheries (5%). Stocking densities for nauplii in larval-rearing tanks did not present significant differences between the hemispheres, with most hatcheries stocking 50 to 125 nauplii per liter.

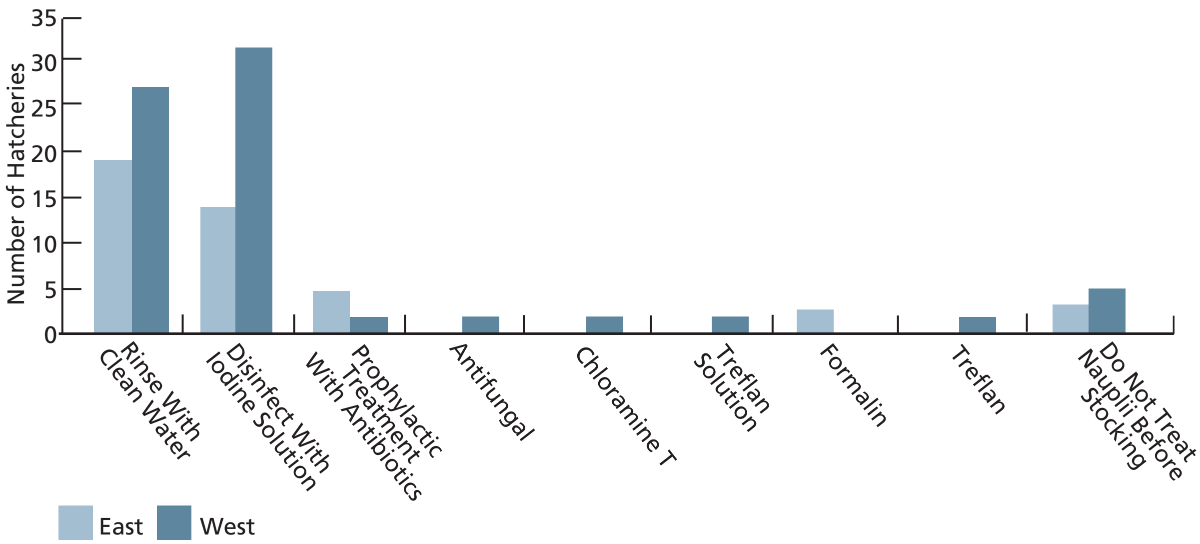



*Figure 2. Respondents' treatment of nauplii before stocking.*

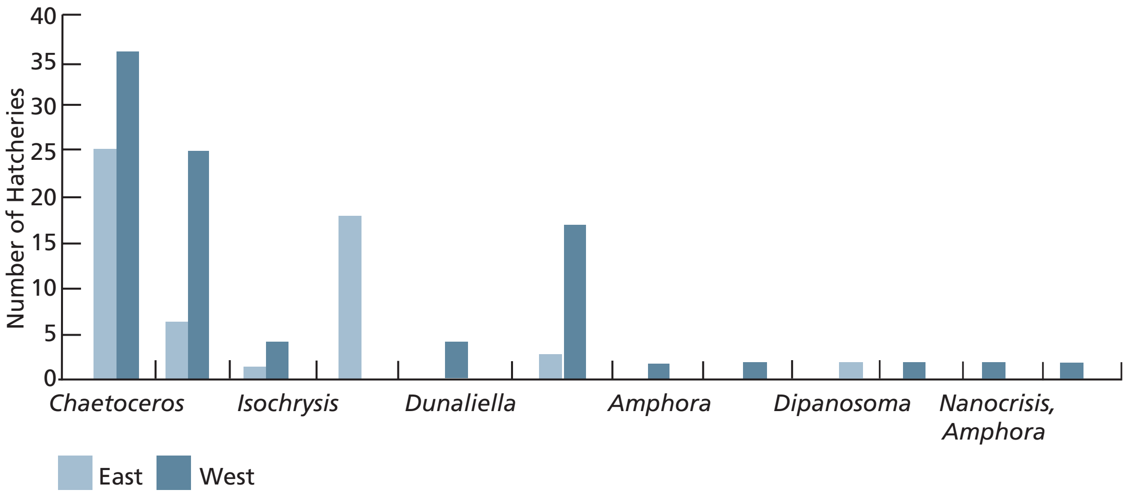



*Figure 3. Microalgal species fed to shrimp larvae.*

## FEEDING PRACTICES

The use of different species of microalgae by hatcheries is presented in Figure 3. The algae *Chaetoceros*, *Tetraselmis*, and *Thalasiossira* were most common in the West, while *Chaetoceros* and *Skeletonema* were most common in the East.

As reported by 43% of the respondents, *Thalasiossira* use in the Western Hemisphere has become more prevalent in the last few years, but 82% of hatcheries in the region still relied on *Chaetoceros* as their primary algal species. In the East, *Chaetoceros* was the primary species at 52% of the respondents' facilities, with *Skeletonema* used at 47%.

This level of *Chaetoceros* use represented a significant increase over previous years, when *Skeletonema* was the primary algal species. Although the relative proportions of algal species may be somewhat skewed, it is nevertheless true that *Thalasiossira* use in the West and *Chaetoceros* use in the East are now more common than in the past.

The algal densities used for larval culture varied by hemisphere. In the West, the modal target density was between 100,000 and 200,000 cells per milliliter, while in the East, it was much lower, in the 20,000 to 50,000 cells per milliliter range. The difference reflected the lower densities used with the larger microalgae *Skeletonema*.

The majority of hatcheries in both hemispheres used the traditional batch culture system rather than continuous culture of algae. About 20% of the hatcheries in both hemispheres used plastic bag systems for large-scale culture of microalgae. Algal pastes used as nutritional supplements or backup for live cultures have gained in popularity in both hemispheres, with 33% and 65% of the hatcheries in the West and East, respectively, reporting their use.

*In this egg-hatching and nauplii-rinsing apparatus, the collector at top has a black cover with a hole to attract nauplii to the light for transfer in flowing sea water to the nauplii collection vessel. Photo courtesy of Unima.*

In the West, it was more common for hatcheries to purchase commercial algae pastes (28% of respondents), and only a small number (5%) concentrated their own. The situation was reversed in the East, where 45% of the respondents reported concentrating their own algae on site and only 20% bought commercial algal pastes. This proportion was likely higher than the industry average, although many hatcheries use dried forms of algae, mainly dried *Spirulina* and *Schizotrychium*, as supplements.

The use of *Artemia* also was investigated in the survey. Typically, *Artemia* cysts constitute one of the most important components of the production cost of shrimp postlarvae, and their price varies greatly from year to year according to supply and demand. The survey was carried out at a time when the price of cysts was in the U.S. $30 to $50 per pound range, while more recently, the price has dropped below $10 per pound.

Microalgae production often begins indoors in bags, (top left), then moves to outdoor bags and mass culture in tanks.

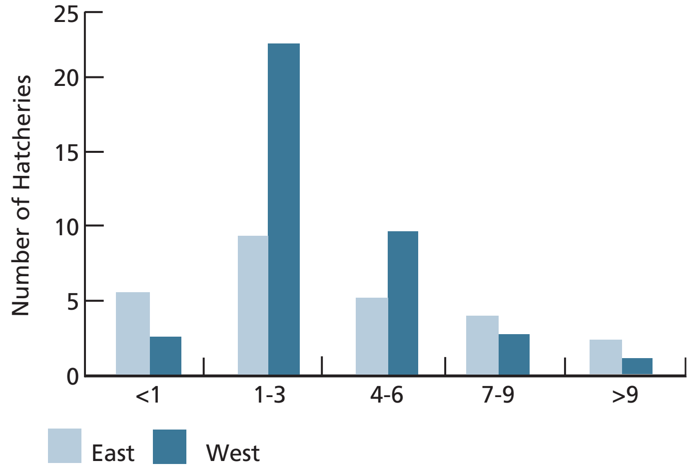



*Figure 4. Reported rates of* Artemia *use (kg* Artemia*/million postlarvae).*

*Larval flake diet. Photo courtesy of INVE.*

A wide range of rates of *Artemia* use was reported (Figure 4), with modal rates in both hemispheres of one to three kilograms *Artemia* per million postlarvae produced. This represented a typical range for periods of high *Artemia* prices, when hatchery managers tend to decrease usage and substitute other feeds, despite a general perception that *Artemia* increase the vigor of postlarvae. Most of the survey respondents reported their use of *Artemia* decreased over the previous two years, which coincided with the price increases.

*Artemia* supplements and formulated larval feeds have been used widely in hatcheries for many years. Only 9% to 10% of the survey respondents reported not attempting any method of *Artemia* reduction. The most common form of *Artemia* substitution or supplementation was with microencapsulated diets. Microparticulate, liquid, and flaked diets were also popular.

*Artemia* enrichment was more prevalent (45%) in the East than the West (30%). In the East, 90% of the enrichment users purchased enrichments mostly from suppliers. In the West, only 27% of users purchased from suppliers, and 21% made their own enrichment media on site. The use of enrichment media in the East may not be as widespread as the survey suggested.

Just 8% to 9% of the hatcheries reported the use of artificial substrates to promote the growth of natural feed organisms.

## NEW INGREDIENTS, COSTS

New hatchery feeds have recently become available. Some of these feeds include "high-tech" ingredients like immunostimulants, probiotics, antibiotics, and highly unsaturated fatty acids (HUFAs). Hatcheries indicated a strong interest for these feeds, especially those containing immunostimulants, HUFAs, and probiotics.

*Pure cultures of beneficial live bacteria can be used to inoculate larval-rearing tanks.*

The typical costs of formulated diets in postlarval production were also studied in the survey. All the respondents indicated a cost somewhere between U.S. $0.10 and $0.70 per 1,000 postlarvae produced. Over half the respondents in both hemispheres reported formulated diet costs between U.S. $0.41 and $0.70 per 1,000 postlarvae. These can be considered typical for shrimp hatcheries worldwide.

## POSTLARVAE CHARACTERISTICS, QUALITY CONTROL

The survey data indicated that hatcheries in the West tended to sell postlarvae in the 5- to 12-day-old range, while the Eastern market was more focused on older postlarvae in the 13- to 20-day-old bracket (Figure 5).

As farmers experience the impacts of postlarval quality on production, there is an increased need for standardization of quality criteria. Most hatcheries in both hemispheres relied on such basic criteria as visible fouling, various stress tests, and postlarval size. A significant proportion of hatcheries utilized tests that required a microscope, such as the evaluation of muscle-to-gut ratio (MGR) and gill development. Although these tests are becoming widespread, their popularity in the survey was probably higher than for the industry as a whole. Results were comparable for both hemispheres, except higher attention was given to gill development in the West, and MGR in the East.

The quality assessment methods performed at hatcheries showed similar trends between the East and West. Not surprisingly, water quality and microscopic analyses were most common. The proportion of hatcheries conducting bacterial plate counts (West 53%, East 64%), antibiotic sensitivity tests (23%, 32%), and bacterial cultures (30%, 23%) was high and corroborated the survey's bias toward the more technologically advanced hatcheries. In particular, 30% and 41% of respondents in the West and East, respectively, reported conducting on-site polymerase chain reaction (PCR) analyses for viruses. In reality, the great majority of hatcheries do not have expensive on-site PCR capabilities.

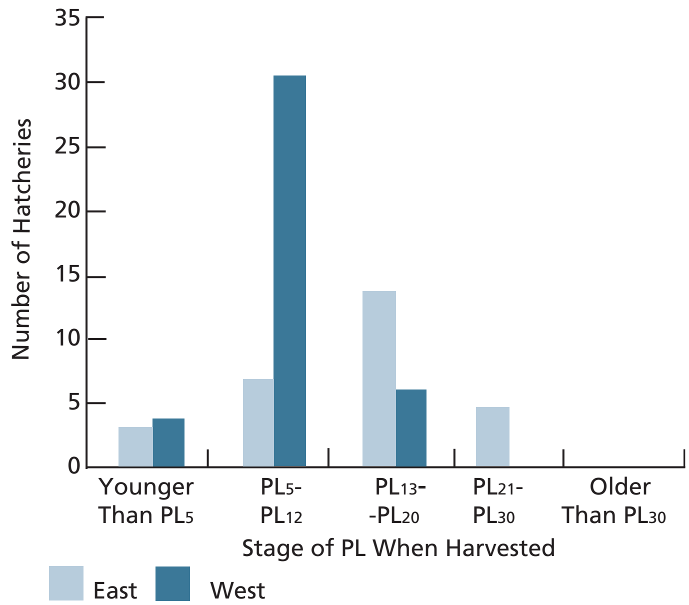



*Figure 5. Growth stage of harvester postlarvae.*

## USE OF ANTIBIOTICS

The use of antibiotics in hatcheries is controversial. The rapid development of resistant bacterial strains and possible antibiotic residuals in shrimp tissue are valid concerns. Certain antibiotics are banned altogether for use in aquatic animal production, while others are regulated as to residue limits and withdrawal periods. Shrimp farmers perceive that indiscriminate antibiotic use has an adverse impact on postlarvae quality.

Recent regulatory actions by the European Union that enforced limits on chloramphenicol and nitrofuran residues in shrimp have farmers and exporters in the East concerned and confused. The regulations have prompted heightened concerns and elimination of antibiotic use in farms and hatcheries. The Global Shrimp OP survey predated these controversies.

In this 2001 survey, 33% of Western and 23% of Eastern respondents avoided the use of antibiotics. Although the accuracy of such data is open to question, it is encouraging that hatchery operators are moving away from the routine application of antibiotics. Five years ago, some antibiotics were widely used in hatcheries, particularly oxytetracyclin, erythromycin, nitrofurazone, and chloramphenicol. The actions of the European Union and increased concern among farmers continue to prompt the reduction and eventual elimination of antibiotic use in hatcheries.

The preferred methods of antibiotic application reported by hatcheries are presented in Figure 6. Of those hatcheries that used antibiotics, the majority stated their applications followed either the first signs of disease (metaphylactic use) or a confirmed diagnosis (therapeutic use). However, a significant proportion stated that their use of antibiotics was intended to prevent the appearance of disease.

## DRYOUT

The majority of hatcheries dried out and disinfected their production facilities periodically in an attempt to prevent the establishment of undesirable bacterial flora. In the West, 76% of respondent hatcheries reported drying out after each production run. The proportion was lower in the East, with 52% of the respondents reporting the practice. Scheduled dryouts reduce or eliminate unwanted bacterial populations, but also represent a loss of valuable production time. Routine dryouts of facilities are used as an alternative to antibiotic use or to overcome the build-up of bacterial resistance.

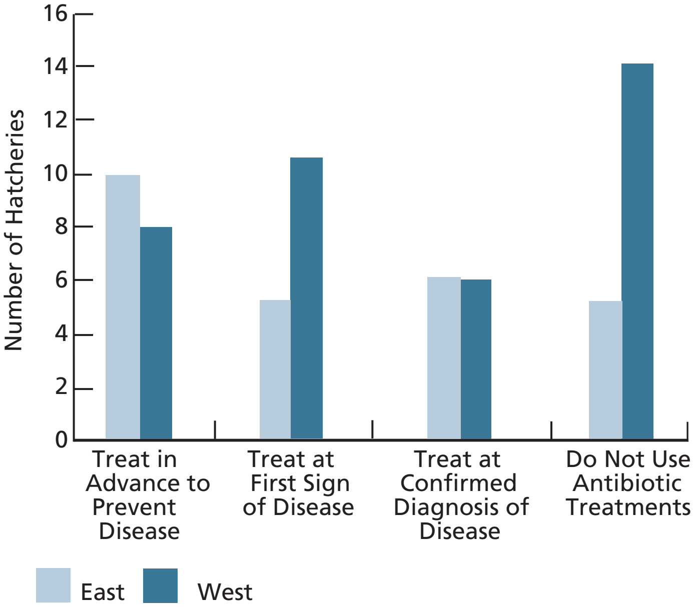



*Figure 6. Preferred methods of antibiotic use.*

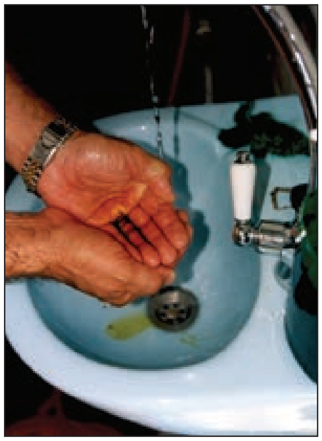
*Routine dryout of larval tanks is a recommended practice.*

Some hatcheries take a different approach, attempting to establish a more benign bacterial ecology by using sanitation practices, disinfectants, probiotics, and other measures conducive to the establishment of a favorable bacterial mix. These hatcheries can run several larval cycles before scheduled dryouts or continuously until problems dictate dryout.

## BIOSECURITY

All the respondents took some precautions to maintain biosecurity. The most common measures were the disinfection of water (West 83%, East 95%) and equipment (80%, 82%). Many (West 78%, East 68%) respondents also reported taking special precautions to control potential virus carriers. In the West, 43% of respondents provided some form of special clothing to hatchery staff, while 55% of the Eastern respondents used special clothes.

Some (West 35%, East 45%) hatcheries took measures to control air flow. Given the level of attention that is apparently paid to biosecurity, the number reporting having written procedures for biosecurity was relatively small (West 60%, East 36%).

*Biosecurity precautions include notices to visitors, hand washing, and equipment rinsing with iodine disinfectant.*

## ANIMAL CONTAINMENT

Releasing hatchery shrimp into the environment could cause undesirable consequences, so it is critical for hatcheries to avoid introducing hatchery animals into wild populations. The most obvious concern is the release of exotic animals, which could theoretically establish themselves and cause problems.

The second is when the genetic makeup of hatchery animals is different from that of the wild populations. Breeding between captive and wild stocks could result in the loss of genetic diversity. The third area of concern would be the introduction of hatchery diseases into the wild.

According to the survey, the prevention of animal escape in the West was addressed by filtration of effluents (61% of respondents) and to a lesser extent effluent disinfection (16%). About 23% of Western hatcheries did not address the issue.

In the East, 36% of the responding hatcheries reported the use of effluent disinfection, and 23% used filtration. However, 41% of the Eastern respondents took no special precautions against the escape of animals.

## HEALTH MANAGEMENT

When asked to rank the most serious disease or health-related problems facing their facilities, the respondents replied with the answers presented in Figure 7. The responses were typical for hatchery operations in both hemispheres.

*These 18-day-old* P. monodon *postlarvae are ready for transfer to a growout pond.*

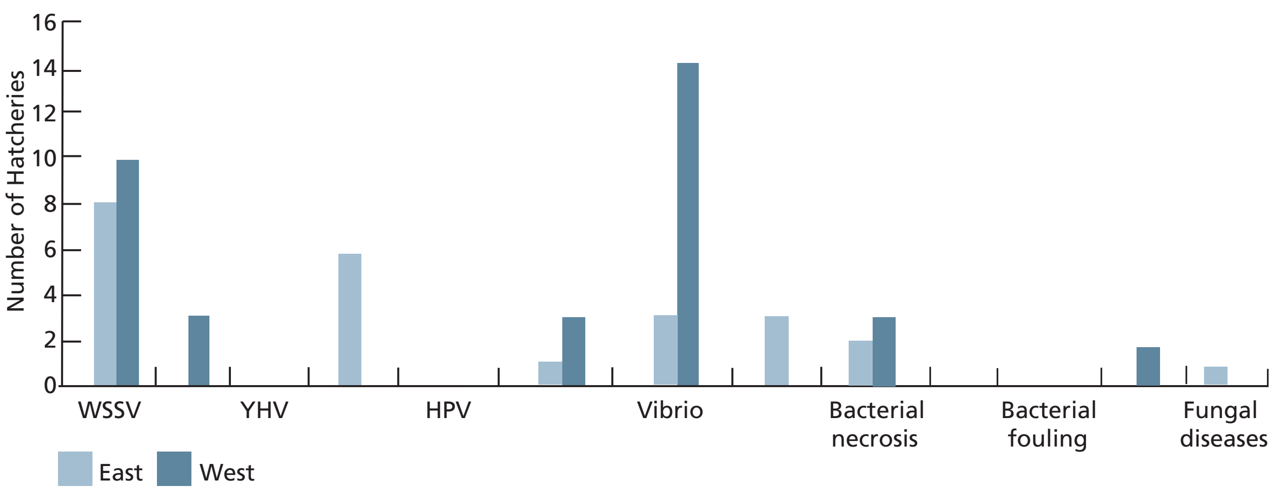



*Figure 7. Most serious health-related concerns of participating hatcheries.*

In the West, bacterial diseases represented the most serious disease concerns, followed by protozoan fouling and fungal diseases. The relatively low importance given to viral pathogens reflected the more extensive nature of Western culture systems and accompanying philosophy exclude them. The survey data preceded the recent popularity of biosecure inland systems, which certainly demand the exclusion of viral pathogens.

In the East, Monodon Baculovirus (MBV) was the top concern, followed by Vibrios and WSSV. The high ranking for MBV may have been due to its role in postlarval quality assessment. Many assessments use the presence or absence of MBV occlusion bodies as a criteria for evaluation.

Indeed, after WSSV, bacterial diseases accounted for most of the health management concerns of Asian hatcheries, where bacterial necrosis and luminous bacteria are frequently cited as major causes of larval production losses. Fungal diseases and fouling by bacteria and protozoans represented the next major concerns of Eastern hatchery producers.

### RESEARCH PRIORITIES

Two key areas, genetics and nutrition, were ranked above other research needs. These were followed by improved disinfection methods, probiotics, and vaccines. Interestingly, antibiotics scored relatively low, again emphasizing the trend toward prevention rather than treatment.

The clear need for further research on the genetics and breeding of shrimp, and on larval nutrition is very similar to the needs identified by many research workers. This suggests that these areas have the potential to provide the most fruitful avenues for public-private sector collaboration and research to improve the efficiency of hatchery operations worldwide.

## Recommendations

This survey revealed that many hatcheries are already implementing systems and procedures that not only produce more high-quality postlarvae, but minimize environmental impacts, as well. Although these trends are highly desirable, Global Aquaculture Alliance and other organizations will continue to emphasize the need for improved hatchery operations.

The following practices are recommended for responsible, efficient hatchery production.

- Hatcheries should rely on domesticated broodstock.
- Monitoring of culture conditions should be implemented to assure a high-quality culture environment.
- Disease diagnosis should be regularly used.
- Effluents should be monitored and treated.
- Measures to prevent animal escape must be implemented.
- Methods for reducing *Artemia* use should be implemented.
- Techniques for testing postlarval quality should be adopted.
- Quality control procedures should be used.
- Antibiotics should be abandoned in favor of sound health management practices that rely upon biosecurity and good water quality management.
- Hatcheries should be dried out after each cycle.

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# HATCHERY

## *Nursery*

GLOBAL AQUACULTURE ALLIANCE

# Nursery

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## Principles

Nurseries – defined as any activity or stage between hatchery and final growout – are important management tools used to give shrimp hatcheries or farms an economic advantage. Nurseries are perceived by many as a means to shorten production cycles in growout ponds and achieve more crops per year. Others believe that nurseries are most useful in regulating the flow of postlarvae (PL) from hatcheries to farms. Nurseries can shorten hatchery cycles and acclimate PL to pond conditions.

Nursery ponds have been used since the 1970s in shrimp-farming operations. Beginning in the 1990s, there was a shift away from nursery ponds to direct stocking with postlarvae.

The original nursery concept was to shorten growout cycles in production ponds by starting off the shrimp in nursery ponds at higher densities. Shrimp held in nursery ponds for 45 days were stocked at 1- to 2-gram size in production ponds. Overall survival was often lower, however, and the desired economic advantage was often lost or diminished. In the past 10 years or so, increased interest has been shown in intensively managed nursery tanks.

The rationale for using nurseries as extensions of hatcheries or on farm sites varies with each situation. In temperate climates, a spring head start for PL in indoor nurseries is often practiced. Delaying the exposure of shrimp to pathogens in untreated pond water is another reason often expressed to justify the use of nursery tanks.

In direct-stocking growout – even with the best management and the use of stocking cages – the real condition and survival of shrimp PL is impossible to know with any great degree of accuracy until some PL are captured during pond sampling or harvest. The problem is that by harvest, significant capital has already been spent on the assumption that the PL would indeed survive and grow at the expected levels.

*Nursery systems generally produce higher overall survival and more efficient capital utilization than single-phase or direct-stock growout systems.*

With current viral disease problems and less-than-absolute guarantees of disease-free seedstock, it is increasingly important to know the quantity, condition, and quality of the shrimp before stocking and investing in four months of constantly increasing feed levels and other resources.

Nursery ponds were in common use in shrimp farms throughout the Americas until around 1993. When Taura Syndrome resulted in significant mortalities in nursery-reared juveniles being transferred to growout ponds, direct PL stocking became the norm. Today – a couple of diseases later – nursery systems are again receiving attention as a potentially important intermediate management strategy between hatchery and growout.

### INTENSIFICATION

Intensification implies a significant increase in stocking density, which demands the use of aeration to maintain dissolved-oxygen levels, filtering of incoming water to prevent predators and disease carriers, and the addition of artificial substrates to increase the surface area available for juvenile shrimp food production and converting their waste products into beneficial feeds or harmless by-products. From an economic standpoint, intensification necessarily implies an economic advantage where production costs per unit shrimp weight are the same or lower than at less-intensive production levels.

## ADVANTAGES OF INTENSIVE NURSERIES

The use of an intensive nursery strategy involving holding shrimp PL in special facilities for 20 to 40 days at very high densities with more precise technical management, feed, monitoring, and water quality is showing it can be a valuable tool in improving shrimp yields and the bottom line.

These nursery systems generally produce higher overall survival rates per production unit area and provide more efficient capital utilization than single-phase or direct-stock growout systems. Intensive nurseries provide greater precision in managing culture conditions, feeding, and biosecurity in the practical exclusion of pathogens, predators, and competitors – thereby creating more efficient utilization of operating capital, particularly feed cost.

Most intensive nursery systems allow more precise management manipulation of juvenile shrimp within practical and advantageous economic boundaries, which may not be practical in larger pond systems. These are some of the advantages of intensive nurseries:

- By reducing the culture area and volume for a crop of juveniles into a series of intensively stocked tanks, a relatively high degree of precision over environmental conditions, water quality, and feeding can be achieved. Dealing in smaller unit areas and volumes increases the economic feasibility of excluding pathogens, predators, and competitors by filtration and/or chemical or biological means.
- Two-stage growout using a nursery phase provides the opportunity to increase biosecurity as a quarantine system and consequently usually produces higher overall survival rates and production per unit area than single-phase growout systems.
- Enclosed nursery systems increase the number of growout production cycles by reducing culture time to market size. From a biomass standpoint, growout ponds are being used more efficiently – not only biologically, but also with greater capital and operating efficiency.
- Greater accuracy in estimating juvenile populations prior to stocking the growout crop. Stocking juveniles permits a more accurate estimate of initial population and biomass, increasing the accuracy of future feeding rates that can become up to 60% of production cost.
- Enclosed intensive nursery systems can further broaden effective water temperatures and resulting stocking windows for seasonal hatchery outputs. This allows greater efficiency for both hatcheries and farms. For farms without hatcheries, intensive nursery head-start strategies can allow the purchase of seedstock in advance of peak demand periods at lower cost and with greater certainty of delivery.
- For shrimp farms in areas of lower salinities, nurseries can be used as acclimation systems.

*Intensive nursery strategies offer precise technical management of feeding, monitoring, and water quality.*

## INTENSIVE NURSERY SYSTEMS

Intensive nursery systems can take several effective forms and configurations. The single defining feature in all intensive nursery systems is that they are housed in an impermeable containment system. This must be a container that can be quickly and completely cleaned and sterilized each production cycle, leaving no residual organics or pathogenic materials from the previous cycle.

Intensive nursery tanks, raceways, and lined ponds provide more control than earthen nursery ponds, and can yield higher survival rates. In general, intensive nursery systems can be divided into two basic categories: lined pond and circular or rectangular tank systems. These two categories can be subdivided into environmentally controlled or ambient systems, and then further into flow-through or recirculating systems. Each system has inherent advantages and disadvantages.

The advantages of outdoor, above-ground tank or lined-pond intensive nursery systems include:

- A culture surface that can be effectively renewed between production cycles.
- A nonporous surface that prevents the residual build-up of toxins, subsurface reduction of metabolites and other organics, and the harboring of pathogenic spores.
- A culture system that can be effectively mechanically fed.

The disadvantages of outdoor systems include:

- Open access to predators and competitor organisms, disease carriers, airborne contamination, and thieves.
- Susceptibility to physical damage by weather and accidents.
- Extreme temperature variability that reduces growth even when temperature averages are "ideal."
- Without shading, extreme light conditions often produce unmanageable algal blooms and system crashes with resulting dissolved oxygen shortages.

Inside nursery systems were first used in areas where the growing season is reduced by less-than-optimum growout temperatures for significant parts of the year. The use of greenhouses or insulated buildings to control temperature can extend the growout season through a process commonly called head starting. This strategy effectively shortens the length of each growout and thereby permits more or longer crops per growing season. Inside nursery systems maintain temperatures near the 28-degree C optimum.

The major advantage of taking intensive nurseries inside is that it creates an isolated environment capable of almost complete physical and biological security. Greater biosecurity makes intensive nursery systems truly valuable tools in improving growout production and economies.

The advantages of controlled-environment intensive nursery systems include:

- A culture system that can be enclosed or covered relatively easily.
- Limited access to predators, competitor organisms, disease carriers, airborne contamination, and thieves.
- Effectively isolated quarantine areas where water and air systems do not cross-contaminate culture systems through diseases borne in water, air, or sprays. In these subdivided areas, disease outbreaks can be effectively identified, treated, or destroyed before the infection spreads to other stock.

  By identifying diseases or poorly performing groups of juveniles in isolated nursery units, continued investment in these animals can be effectively monitored and analyzed.
- An environment of more constant growth temperatures through conserving or gathering heat. In temperate climates, enclosed nursery units can be selectively maintained as juvenile stocks are placed into growout, thereby reducing energy requirements.
- Cover over culture systems allows light control and better management of algal and bacterial blooms.

Some disadvantages of inside intensive nursery systems are:

- Increased capital cost for the facility and effective juvenile transport system, though effective systems should rapidly pay back costs in increased production efficiencies.
- Greater and more sophisticated management experience requirements. Since many of these systems recirculate, knowledge of managing and maintaining recirculating systems is also required.
- Greater dependence on electrical and mechanical systems, including emergency electrical backup.

## BASIC INTENSIVE NURSERY CONFIGURATIONS

***Circular tanks.*** Since round tanks have excellent circulation and energy efficiencies, many intensive nursery tank systems are round, with a central drain. They are made of fiberglass, concrete, or the most locally cost-efficient materials. Some require plastic liners to be impermeable and sanitary.

However, large round systems loose some of their most attractive physical attributes. As diameters increase, more energy is spent to maintain higher flow velocities to scour and entrain solid waste. At tank diameters of 30 to 40 meters, the velocities become excessive for the shrimp.

*Due to circulation and energy efficiencies, many nursery tanks are round.*

*Raceway nurseries require maintenance that includes the regular removal of solid waste from their bottoms.*

***Raceways.*** Oval or plug-flow raceways are typically 33 to 66 meters long by 5 to 9 meters wide, with depths of 0.7 to 1.0 meter. While they fit nicely into commercial greenhouses and the conventional free span of hard structures, they require more energy than tanks to generate the water flow necessary to deliver solid waste to designated removal points.

Oval raceways have some characteristics of round tanks and are better able to fit into rectangular spaces such as commercial greenhouses. To maintain organized flow, oval raceways are usually divided by a center wall that stops before the ends. Oval raceways usually have two drains and two points to pick up solid waste.

Plug-flow raceways are long, rectangular tanks where the flow enters one end, uniformly traverses the length of the raceway, and exits the far end. Since the solid wastes are generally picked up at the discharge end, waste becomes concentrated at the far end of the tank.

Plug-flow systems are simple to design, but often difficult to manage due to their inability to effectively remove solid waste. Both oval and plug-flow intensive nurseries often require high levels of maintenance, including the "vacuuming" of solid waste from their bottoms – where very small juvenile shrimp gather wall to wall.

## AERATION

Aeration is very important in intensive nursery systems to not only provide oxygen to the shrimp for effective feed utilization and growth, but also oxidize the systems' liquid, solid, and gaseous wastes.

Aeration, water circulation, and flow in circular tanks and oval or plug-flow raceways can be provided by paddlewheels, spray from high-pressure pumps, and/or air-lift pumps. Systems using both spray bars and air-lift pump systems have the advantages of redundancy in the case of mechanical failure.

*Aeration provides oxygen to shrimp and oxidizes system wastes, as well.*

## WATER QUALITY

Temperature and water conservation in intensive nursery systems is very important. Where outside water sources may be contaminated, reusing water resources become cost essential to rear juveniles past their most disease-susceptible first 40 days. Optimum water quality must be insured by using appropriate water filtration and conditioning as necessary.

Above-ground nursery systems are typically stocked at 500 to 10,000 postlarvae/meter, depending on harvest size and biomass.

## NURSERIES EXTEND HATCHERY PERIOD

In Asia, a general practice with *P. monodon* has been to stock production ponds with at least $PL_{18}$. Hatcheries often harvest $PL_3$ to $PL_5$ and transfer them to larger indoor or outdoor tanks, where the stocking density is lowered. Some nursery operations specialize in rearing postlarvae to the larger sizes desired and acclimating them to pond salinity.

Due to the well-known processes of organic waste decomposition to ammonia to nitrite to nitrate, stocking postlarvae in clear water is not generally advisable. Bacterial processes are slower to mature in clear water.

Nursery systems usually rely on algae blooms as a practical way to deal with this problem. Algae quickly detoxify nitrogenous wastes and can serve as a source of nutrition for shrimp larvae. With the growing scarcity and cost of *Artemia*, transferring early-stage postlarvae to nursery tanks can reduce consumption.

*Shrimp postlarvae held in nursery tanks should be robust and better able to withstand the rigors of life in ponds.*

## IMPROVED SURVIVAL, SHORTER CYCLE

In hatchery operations, the key to success is to improve overall survival and produce a desirable product that survives better in clients' production ponds. It is important to hatchery operators to reduce costs through improvements in operating efficiency.

Nurseries can effectively cut one week off the typical production cycle of $PL_{12}$ *Litopenaeus vannamei* by moving $PL_5$ to outdoor nurseries. Survival to $PL_{12}$ is higher when compared to leaving larvae to attain that stage in hatchery tanks.

$PL_5$ stocked in a well-prepared nursery tank can then be sent to the farm as $PL_{12}$ in a more robust condition. Postlarvae held to that stage in nursery tanks generally show more advanced gill development, which is important to acclimation to farm conditions.

## NURSERIES AS PART OF FARM OPERATIONS

Nursery tanks are often located at farm sites, where they serve to acclimate larvae to farm water conditions. It may not be practical or economical to ship older postlarvae from the hatchery, because they stress more easily and cannot be concentrated in small containers due to the increased biomass.

## NURSERY VS. DIRECT STOCKING

Older farm-conditioned postlarvae should have higher survival in growout ponds. Properly managed, shrimp postlarvae held in nursery tanks should become more robust and better able to withstand the rigors of life in earthen ponds. Feeding accuracy and feed conversion can be expected to improve. Besides saving money, improved feed conversion can lead to improved water quality and lessened environmental impact.

## REGULATED SUPPLY OF SEEDSTOCK

Storing postlarvae in nursery tanks at farms is a means to provide a regulated supply of animals to stock the growout ponds. Ponds are not always harvested on the programmed date. Varied growth rates, market considerations, changing weather, supply delays, work holidays, and other factors make it difficult to maintain a steady flow of postlarvae from the hatchery to the farm. Since industrial-scale shrimp farms have a great need to maintain a flow of product to processing plants, a ready supply of postlarvae can improve efficiency and profitability.

# Survey

## IMPROVED POND SURVIVAL

Respondents to the Global Shrimp OP Survey stated that the top advantage of using nursery tanks was to improve pond survival. Sixty-two percent stated that nursery tanks were primarily used as a means of producing larger, more robust postlarvae that survive better in production ponds.

Stocking rates in nursery tanks were reported by 53% of respondents in a range of 10 to 50 animals per meter (Figure 1). The lower stocking rates of nursery tanks compared to typical hatchery harvest densities result in less stress to the postlarvae and less management intensity.

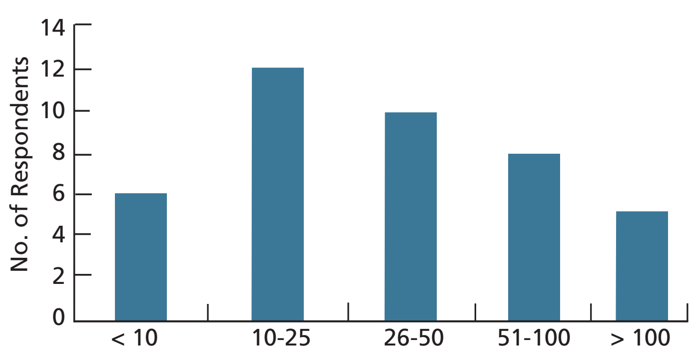


*Figure 1. Reported stocking density (animals/liter) in nursery tanks.*

Postlarvae held in nursery tanks typically have better color, size, and activity that similar-aged postlarvae from the hatchery. Ninety-three percent of the survey participants used animal size and condition as indicators of health status, while 76% utilized overall activity as a health criterion. Pigmentation was considered important by 50% of those who replied to the survey.

Nursery tanks are used to stock older and hardier postlarvae into production ponds. Sixty-two percent of the responding nursery tank operators held their larvae past the $PL_{17}$ stage (Figure 2).

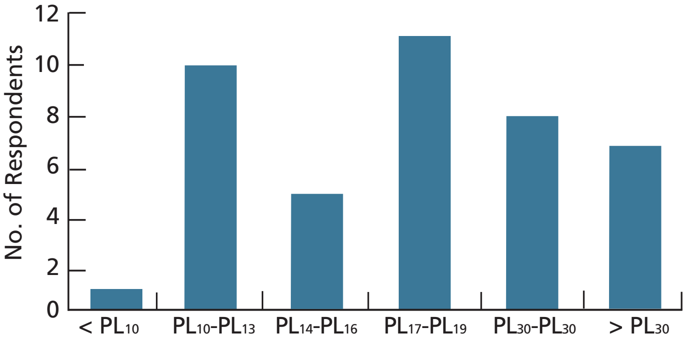


*Figure 2. Age PL are transferred to ponds.*

## NURSERY TANKS IMPROVE HATCHERY EFFICIENCY

The second top advantage selected in the survey was to improve hatchery efficiency by shortening the hatchery cycle. Nursery tanks were important to 42% of respondents as a means to move young postlarvae (most commonly reported to be $PL_{3-6}$) from the hatchery to nursery tanks, thus reducing the typical hatchery cycle by seven days (Figure 3).

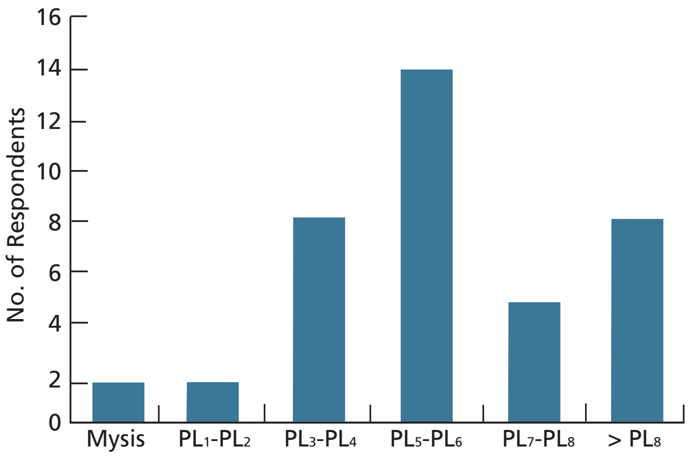


*Figure 3. Age of postlarvae stocked into nursery tanks.*

Moving the younger postlarvae out of the hatchery also results in reduced *Artemia* consumption. Although 71% of respondents said they feed *Artemia* nauplii in their nursery tanks, there is a transition to less-expensive nursery dry diets. Seventy-three percent stated they used special nursery diets, while 40% used less-expensive finely ground pond feeds (Figure 4.).

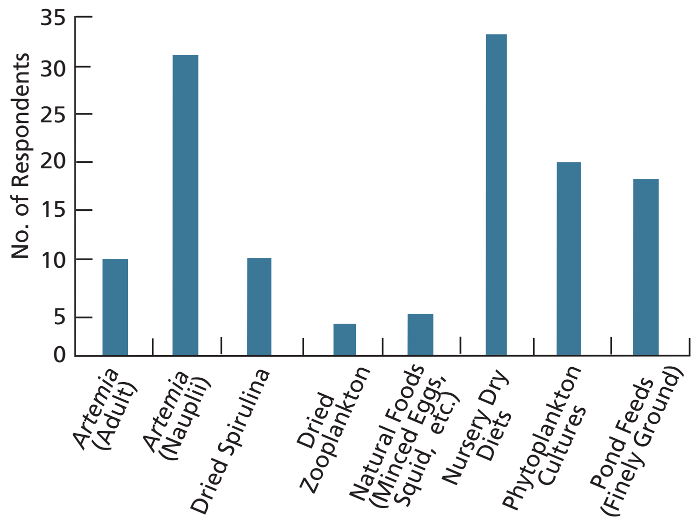


*Figure 4. Feeds used in nursery tanks.*

*Survey respondents used a variety of nutritional sources to feed their young shrimp.*

## GOOD SURVIVAL RATES

Sixty-one percent of respondents achieved survival rates of over 76% in their nursery tanks, with 33% reporting survival over 85% (Figure 5). Although survival is important, high survival is not essential to justify using nursery tanks as part of a production strategy. The importance of nursery tanks is the resultant improvement of survival and growth in the final growout phase.

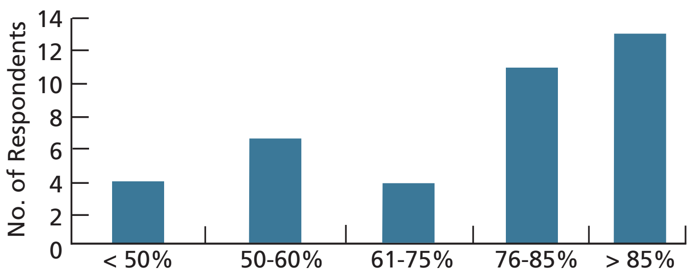


*Figure 5. Typical survival rates (%) reported for nursery tanks.*

## ACCLIMATION

Fifty-seven percent of survey participants stated an advantage of nursery tanks is to acclimate postlarvae to farm conditions. This implies that nursery tanks are often located at farm sites. Postlarvae can be acclimated to farm water conditions while they are reared to a larger size. Thirty-eight percent of respondents used a slow salinity acclimation rate of 1 to 3 ppt per day, which can be accomplished with little effort and stress in nursery tanks (Figure 6).

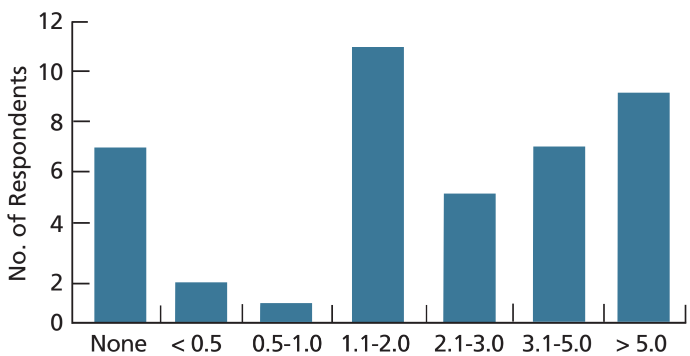


*Figure 6. Reported rates of salinity acclimation (ppt/day) in nursery tanks.*

Fifty-one percent thought nursery tanks are useful to regulate the flow of postlarvae from hatcheries to ponds. Due to delays in harvesting ponds, slower-than-expected growth rates, or weather, postlarvae can be inventoried until the ponds present ideal conditions for stocking.

Forty-nine percent of the respondents listed the fact that nursery tanks improve pond efficiency by shortening the growout cycle as an advantage.

## EAST VS. WEST

Although the numbers of respondents were almost equal from the Eastern and Western Hemispheres, some notable differences were reported in the survey.

The East favored square nursery tanks made of concrete, while farms in the West favored rectangular or raceway configurations with plastic liners (Figure 7). Seventy-one percent of Eastern nursery tank operators reported they used concrete or painted concrete tanks.

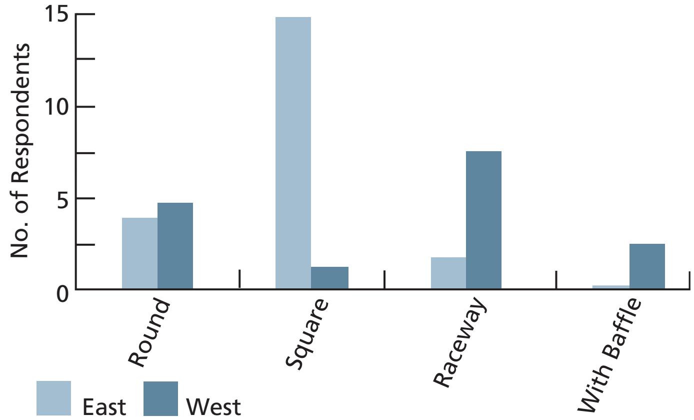


*Figure 7. Shape of nursery tanks.*

Of the Eastern respondents, 39% reported their tanks were blue in color, while black tanks were used by 68% of the Western respondents. Perhaps the main reason for this color difference was that 62% of Western respondents reported using plastic liners, which most often come in a black color for sunlight resistance.

Tank sizes were also very different. The West preferred larger tanks, with 57% of the respondents reporting tank sizes of 21 to 50 tons. Fifty-eight percent of East respondents had tanks of 5 to 20 tons.

An obvious reason for this difference is the varied pond size between East and West. Nursery tanks should be sized to the ponds that will be stocked. The smaller pond sizes in the East require smaller nursery tanks.

The survey reflected a greater level of sophistication or longer history battling White Spot Syndrome Virus in the East. Sixty-three percent of the Eastern respondents chlorinated the water used in nursery tanks compared to 23% of the Western respondents (Figure 8).

Of interest is that 46% of the Eastern survey participants routinely monitored alkalinity, while only 10% of the Western nursery tank operators were concerned with this measurement. Field observations and reports have indicated there may be a correlation between alkalinity and control of White Spot.

Probiotics were reported to be used by 38% of the East respondents, while only 18% of West respondents used them (Figure 9). Probiotics are bacterial cultures and organic substances such as molasses and grain products that are added to water to stimulate desired bacterial growth. Probiotic additives are used to control ammonia and retard the growth of pathogenic bacteria.

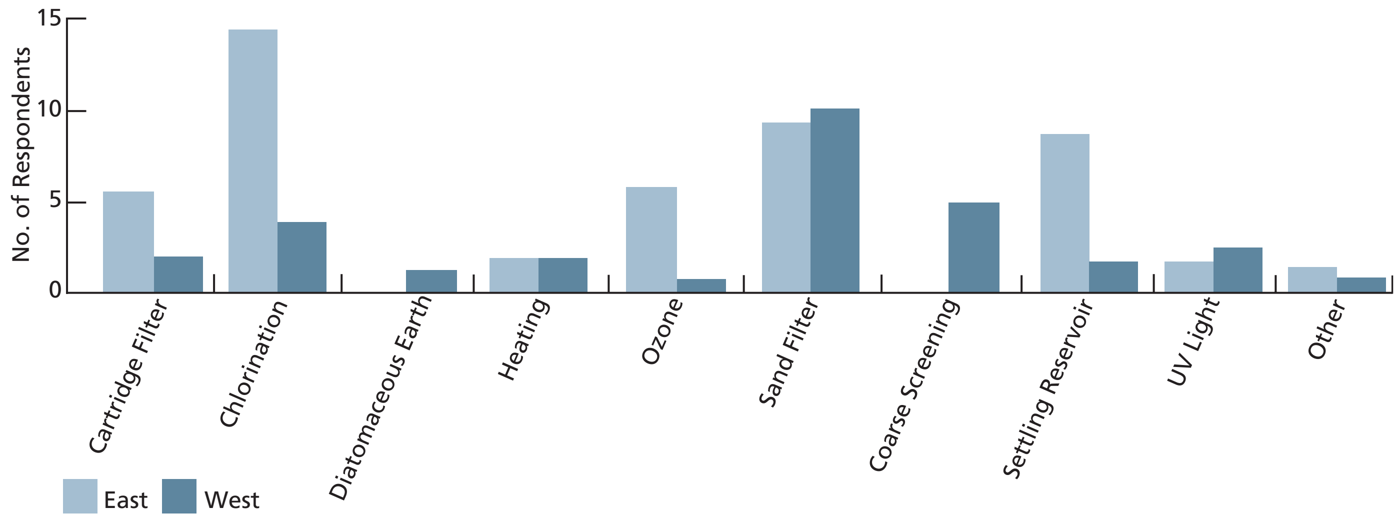


*Figure 8. Preparation of water in nursery tanks.*

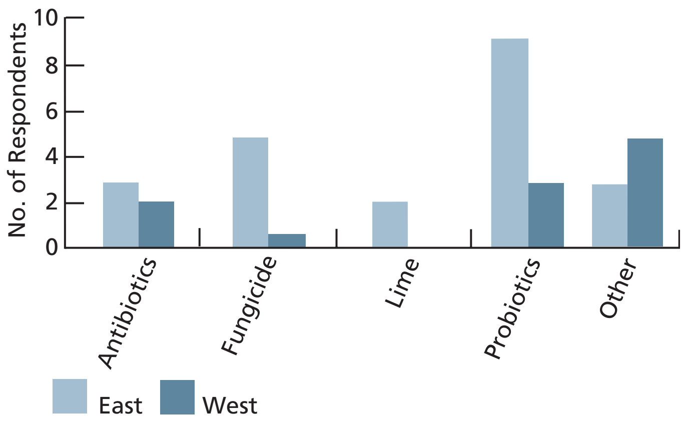


*Figure 9. Additives routinely used in nursery tanks.*

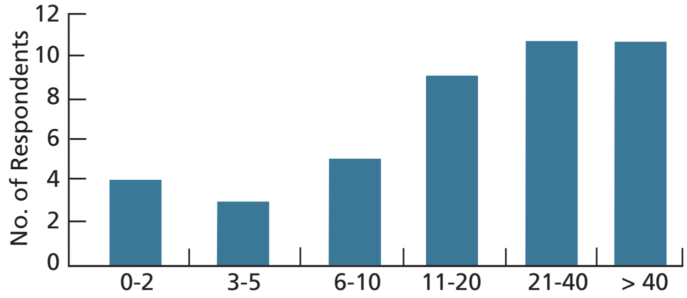


*Figure 10. Typical water exchange (%/day) in nursery tanks.*

## ALGAE BLOOMS

Of the respondents, 32% stated they did not stimulate algae blooms. The majority of respondents used inorganic nutrients to stimulate algae growth in their nursery tanks. Algae blooms are useful to many operators because they quickly establish stable water conditions. Algae can detoxify nitrogenous wastes and provide a supplemental source of nutrition.

On the other hand, algae blooms can crash, with a resultant spike in ammonia that can stress or weaken postlarvae. The probiotic approach, where bacteria are used to stabilize water quality, takes effect more slowly but may give more consistent results.

## WATER EXCHANGE STRATEGY

Forty-eight percent of the survey participants exchanged less than 20% of culture water per day. Twenty-six percent exchanged 21 to 40% per day, while the remaining 26% exchanged more than 40% per day (Figure 10).

This reflects the wide range of opinions and management strategies on controlling water quality. Changing a lot of water is effective in controlling water quality, but some believe that managing the algal and bacterial populations is a more appropriate strategy.

## AERATION SYSTEMS

Sixty-three percent of respondents used air diffusers in their nursery tanks, while 35% used air lifts. Air systems should also accomplish the task of preventing sedimentation. Accumulated sediments can become anoxic and release toxins into the water.

## RESEARCH PRIORITIES

Respondents gave equal weight to water quality and feeds as the highest priorities for research. Probiotics were also mentioned as a priority by 69% of survey participants.

*Juvenile harvest.*

## Recommendations

Intensive, biosecure nursery systems in tanks and raceways are more difficult to manage than standard growout ponds. However, the benefits derived from a two-phase growout strategy using a nursery system followed by final growout to market size can result in significantly higher production and profitability.

The authors expect an increased incorporation of this strategy at shrimp farms around the world – not just in operations located in semitropical and temperate regions, where two crops per year are not possible without a nursery phase, but increasingly in tropical areas where they will be employed primarily as biosecurity and disease management tools.

The main problem with the operation of intensive nursery tanks and raceways is the rapid build-up of metabolic wastes and resulting biological oxygen demand, and the need to remove the wastes through high exchange of filtered, recirculated water or flow-through water. With the increased stress created by higher densities, immunity is often weakened and opportunistic disease outbreaks are more likely. Also, as density increases, adequate food levels with more complete nutrition must be maintained around the clock.

Systems that are not well designed, operated, and managed may experience higher and varying degrees of mortality due to handling stress during the relocation of shrimp to final growout systems. This is normally the result of ineffective methods of quantifying and transporting juveniles from the intensive nursery systems to their respective growout ponds.

Many farmers would like to locate their nursery systems at their growout ponds, where they can simply drain the nursery tanks or ponds into respective growout ponds. This proximity, however, effectively cancels out the biosecurity benefits that the isolation of the nursery provides. Practical experience also indicates that with even slight survival variations, nursery crops can seldom provide the exact growout stocking number required. Consequently, some portion of the intensive nursery crops will often need to be transported to a more appropriate stocking location.

*The location of nursery tanks near production ponds provides added efficiency.*

Shrimp growth is highly dependent on stocking density and water quality. Separating density-related limitations from water quality and nutrition is very difficult, and densities must be reduced if larger animals are desired.

Careful monitoring of water parameters, particularly dissolved oxygen, pH, and metabolite levels, is critical. High-density nursery systems have much shorter biological reaction rates due to the higher ratio of biomass per culture volume, which creates smaller reserves of oxygen and pH-buffering ability. Nursery systems must be closely watched to prevent massive mortalities.

## For Additional Information

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# FARM

# *Pond Preparation*

GLOBAL AQUACULTURE ALLIANCE

# Pond Preparation

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## Principles

Pond preparation refers to those steps taken by shrimp producers to assure that pond bottom soil and water provide a good environment for stocked postlarvae. The availability of natural food organisms, good-quality soil and water, and absence of disease organisms promote high survival and rapid growth of the young animals. Since pond preparation is a critical aspect of shrimp culture, successful shrimp farms usually have strict protocols for preparing ponds for stocking.

The basic objectives of pond preparation are to:

- Oxidize organic wastes and reduced inorganic compounds that accumulate in pond bottoms during the growout period.
- Eradicate predators, pathogens, and vectors of pathogens that may be present from the previous culture cycle or enter before the pond is stocked for the next cycle.
- Improve soil pH and alkalinity of the water.
- Enhance the availability of natural food organisms before stocking.
- Remove or redistribute sediment as necessary.

Pond preparation plays a particularly important role in shrimp culture because shrimp live on pond bottoms. Water quality near the bottom can deteriorate in response to adverse soil conditions that result from the accumulation of wastes in the culture system. Shrimp are extremely susceptible to diseases, so care should be taken to eliminate disease organisms from the previous crop and prevent the entry of disease agents during pond preparation.

Rigorous pond preparation requires increased the direct costs of material and labor, and opportunity costs while ponds are out of production during preparation.

Most pond preparation practices are derived from commonly accepted methods used in agronomy and animal husbandry. They are based on common-sense principles and years of experience. Very few studies have systematically evaluated specific practices, but there is general consensus that pond preparation should accomplish the objectives listed above.

*Typical pond bottom soon after harvest.*

## Survey

One hundred seventy-five farms participated in the Global Shrimp OP survey on Pond Preparation. Of the participants, 76% were from the Eastern Hemisphere and 24% were from the Western Hemisphere. The survey sought information about pond soil characteristics; drying, tilling, and liming of pond bottoms; methods for removing predators and disease organisms from incoming water; and pond fertilization techniques.

### POND SOILS, SIZES

About 39% of the farms had silty or sandy soil, while 34% had clay soil (Figure 1). There was a higher incidence (24%) of loamy soils in the East than the West (5%). Only one farm in the survey was located on acid sulfate soil.

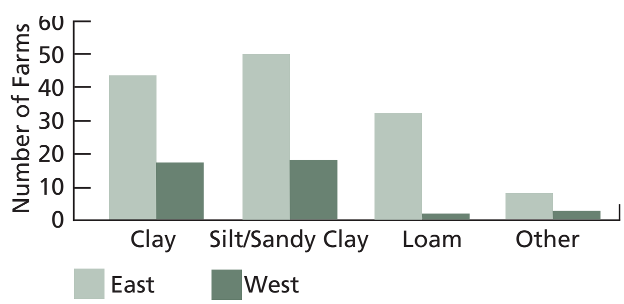


*Figure 1. Soil type reported by survey participants.*

Generally, ponds in the East were smaller (0.5 to 1 hectare) than those in the West (5 to 10 hectares). Small ponds are easier to drain and treat than large ponds.

## POND BOTTOM PREPARATION

***Drying.*** As practiced by 84% of survey respondents, allowing time for empty pond bottoms to dry was the most common method of pond preparation. The bottom should be thoroughly dried in all areas and cracks should develop in the soil. However, overdrying inhibits the natural microbial decomposition of organic matter and should be avoided. When dust is seen when a handful of soil is tossed into the air, the soil is too dry.

If sediment is deep, it may not dry thoroughly. The surface can become dry and inhibit the evaporation of moisture from deeper in the soil mass. Thus, it may be necessary to remove sediment from some areas of pond bottoms.

*After dryout, pond bottom soil appears fairly uniformly cracked.*

Drying pond bottoms is not always possible. Some bottoms do not drain properly, and they cannot be dried thoroughly in rainy seasons. Nearly 17% of farmers in the survey reported that they dried pond bottoms only during dry seasons. This practice was more prevalent (46%) in the West than the East (12%). Ponds with acid-sulfate (pyritic) soils should not be dried because it results in the oxidation of iron pyrite, formation of sulfuric acid, and severe depression of soil pH.

When complete drying is not possible, farmers often use a wet method of cleaning bottoms. The most common method of wet cleaning in the East involves flushing the pond with clean water to wash away the wastes.

Farmers in the West usually treat with chemicals such as chlorine compounds and burnt or hydrated lime. About 46% of the respondents in the West reported such treatments, while only 17% of the respondents in the East used them. Since ponds in the West are generally larger than those in the East, washing and drying ponds are easier to accomplish in the East.

There are advantages and disadvantages to both methods of pond cleaning (Table 1). No formal comparisons between wet and dry cleaning exist, but we feel the benefits of pond bottom preparation are greatest when bottoms are dried and tilled.

*Tilling pond bottoms breaks up the soil and sediment to increase their exposure to sunlight and air.*

***Tilling.*** The purpose of tilling is to enhance the oxidation of organic matter by pulverizing the soil to increase the exposure of wastes to sunlight and air. Bottom soil cracks into column blocks that can appear completely dry. However, the soil mass inside the block often is still wet. Tilling breaks the blocks to improve drying and oxidation.

Tilling the upper 5 to 10 centimeters of soil is most important, for waste from the previous crop accumulates in this layer. The survey showed that only 29% of all farms employed tilling. Only 25% of the farms in the East tilled ponds, while 41% of farms in the West used the practice. This difference may be attributed to the differences in farm and pond sizes. The larger ponds in the West are more conducive to the use of tractors and provide the economy of scale necessary to own or rent the tilling equipment.

*Table 1. The relative advantages and disadvantages of dry and wet methods of removing waste from ponds.*

| Variable | Dry Method | Wet Method |
|---|---|---|
| Time taken | Slow or impossible in wet season | Quick, possible in any season |
| Cost | Depends on area, usually higher | Depends on area |
| Efficiency of solid waste removal | Variable | Good |
| Removal of waste within sandy soil | Variable | Good |
| Form of waste | Solid, easy to handle | Suspension, difficult to handle |
| Acid sulfate soils | Needs careful management | Less oxidation and leaching |
| Sterilizing effects | Variable | Requires additional lime |
| Disposal of waste | Needs site for dumping | Requires settling pond |

*Liming improves the pH and alkalinity of ponds.*

***Liming.*** The term liming is used to describe the application of agricultural limestone, marl, burnt lime, hydrated lime, or other basic substances to soils. The primary purpose of liming is to improve the pH and alkalinity of the ponds. But liming also can be used to oxidize wastes and disinfect bottoms.

Agricultural limestone, the most common liming material, is made from limestone or quarried and crushed sea shells. Agricultural limestone can be calcitic (primarily calcium carbonate), dolomitic (consisting of nearly equal mixtures of calcium and magnesium carbonates), or a mixture of calcium and magnesium carbonates in less than 1:1 proportions. All forms of agricultural limestone are suitable for use in ponds, but the raw material should be finely ground.

Agricultural limestone neutralizes acidity and improves the buffering capacity of soils. The survey found that about 30% of the farms used less than 500 kilograms of lime per hectare, and 26% used 500 to 1,000 kilograms of agricultural limestone per hectare during pond preparation.

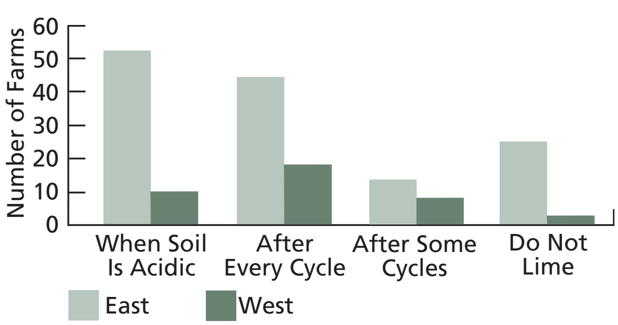


*Figure 2. Liming frequency reported by survey participants.*

There was little difference between the two hemispheres in the amount of lime used. Forty-five percent of farms in the West limed pond bottoms after every production cycle, while only 33% did so in the East. Liming only when soil pH was acidic was more common in the East than the West (Figure 2). Table 2 shows recommended lime applications based on soil pH.

*Table 2. Liming recommendations based on soil pH.*

| Soil pH | Quantity of $CaCO_3$ Lime (kg/ha) | Quantity of $Ca(OH)_2$ Lime (kg/ha) |
|---|---|---|
| Above 7 | 0 | 0 |
| 6-7 | 1,000 | 500 |
| 5-6 | 2,000 | 1,000 |
| Below 5 | 3,000 | 1,500 |

Burnt or quick lime is made by burning limestone at very high temperatures (800 to 900 degrees C). Slaked or hydrated lime is made in the same manner, but water is added after burning. The properties and uses of burnt and hydrated lime are similar.

Lime can serve the same purpose as agricultural limestone, but initially increases pH to a higher level than can be achieved with agricultural limestone. When applied at 1,000 to 2,000 kilograms per hectare, it can increase pH enough to kill microorganisms and disinfect ponds.

The survey did not request specific information on the use of burnt and hydrated lime. It should be noted that lime is highly reactive and caustic. It can cause high pH in ponds and be hazardous to workers.

## FILL WATER

Precautions to prevent the entry of predators, diseases, and excessive amounts of settleable solids are required while filling ponds with water for a new culture cycle. Conventional precautions include filtering the inlet water through a coarse net to prevent the entry of predators. If incoming water is high in suspended solids, it should first be pumped into a sedimentation pond for solids removal before transfer to culture ponds.

Treatment of pond water with chemicals – mainly natural products such as rotenone and tea seed cake – to eliminate predators before stocking is often an integral part of pond preparation. With the advent of serious disease problems, it has also become prudent to pass water through fine filters before introducing it into ponds.

Filters with mesh openings as small as 200 microns are used to remove pathogens and their vectors. A series of progressively finer filters installed between the intake point, reservoir, and ponds is employed at many farms. Sediment ponds also are becoming a regular feature in modern farms to provide initial water treatment, maintain water levels, or effect water exchange.

About 29% of the respondents in the survey reported they did not treat incoming water (Figure 3). Sedimentation was used by 46% of respondents, screening was used by 41%, and only 22% used chemical treatments. While farms in the West relied more on screening (60% versus 36%), farms in the East relied more on chemical treatments (27% versus 3%).

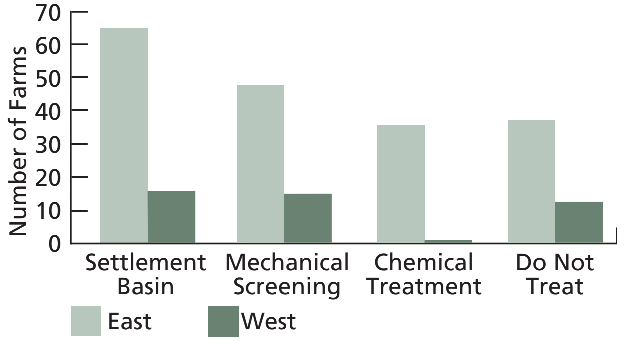


*Figure 3. Water treatment reported by survey participants.*

Chlorine usually is applied in the form of calcium hypochlorite. Chlorination should be done two or three days after filling because of its adverse effect on plankton blooms. The application rate is 15 to 20 milligrams of active chlorine per liter of water, which can be attained using 25 to 30 milligrams of calcium hypochlorite per liter. Roughly 32% of respondents in the East and 45% of those in the West practiced chlorination.

*Gas chlorine cylinders controlled by flow meters treat pond inlet water.*

## FERTILIZATION

It is important to have a healthy bloom of plankton in ponds before stocking so that natural food organisms are available to the newly stocked postlarvae. Whether fertilization is required during pond preparation depends on the nutrient concentrations in the water.

*Table 3. Common commercial fertilizers and their nitrogen and phosphorus content.*

| Fertilizer | Nitrogen (%) | Phosphorus (%) |
|---|---|---|
| Urea | 45 | 0 |
| Ammonium nitrate | 33-35 | 0 |
| Ammonium sulfate | 20-21 | 0 |
| Ammonium phosphate | 11 | 48 |
| Diammonium phosphate | 18 | 48 |
| Calcium nitrate | 45 | 0 |
| Sodium nitrate | 16 | 0 |
| Super phosphate | 0 | 18-20 |
| Triple super phosphate | 0 | 44-54 |

Excessive concentrations of nutrients result in excessive phytoplankton blooms that crash and cause severe water quality problems. Only 8% of the farms that responded to the survey reported the nutrient concentrations in their water source were high, while 65% reported the concentrations were moderate, and 27% reported they were low. Consequently, a majority (68%) of the farms fertilized their ponds during preparatory stages. Fertilization was more common in the West (83%) than the East (63%).

***Nitrogen fertilization.*** About 50% of the farms did not have a target nitrogen concentration for fertilization. Among those that did, a majority (43%) targeted a concentration of 0.5 to 1 milligram per liter, 22% targeted 1 to 2 milligrams per liter, and 31% targeted less than 0.5 milligram per liter. Among the survey participants, 12.5% did not fertilize with nitrogen.

The commonly used nitrogen fertilizers and their nitrogen content are listed in Table 3. Urea was the top choice of farmers worldwide – 54% used it as a nitrogen source. Other nitrogen sources were ammonium nitrate (11%), diammonium phosphate (11%), calcium nitrate (5%), ammonium sulfate (5%), and sodium nitrate (4%).

***Phosphorus fertilization.*** Nearly 44% of the farms participating in the survey did not have a target phosphorus concentration for fertilization. Among those that did, a majority (42%) targeted a level of 0.1 to 0.2 milligram phosphorus per liter of water, 30% targeted less than 0.1 milligram per liter, and 24% targeted more than 0.2 milligram per liter. About 22% of participants did not fertilize with phosphorus.

Table 3 shows the commonly used phosphorus fertilizers and their phosphorus content. Triple super phosphate was the primary choice of farmers worldwide. About 36% used it as a phosphorus source. Other phosphorus sources were diammonium phosphate (14%) and phosphoric acid (1%).

***Organic fertilization.*** Organic fertilizers are used widely in shrimp pond preparation in both hemispheres. They have low cost and easy availability, and decompose to release nutrients slowly. They provide nutrients other than nitrogen and phosphorus, as well as substrate for the growth of microbial food organisms.

These advantages are somewhat offset by a few disadvantages. Organic fertilizers have a low concentration of nutrients and may not be cost-effective. They increase the oxygen demand in ponds by increasing microbial activity and are less predictable in terms of nutrient content and release.

The survey found that 64% of the farms used organic fertilizers, and about 40% used them during pond preparation (Figure 4). Animal manure topped the list (29%), closely followed by molasses (26%), grain by-products (18%), and animal by-products (9%). Fewer farmers in the West than the East used manures (10% versus 34%).

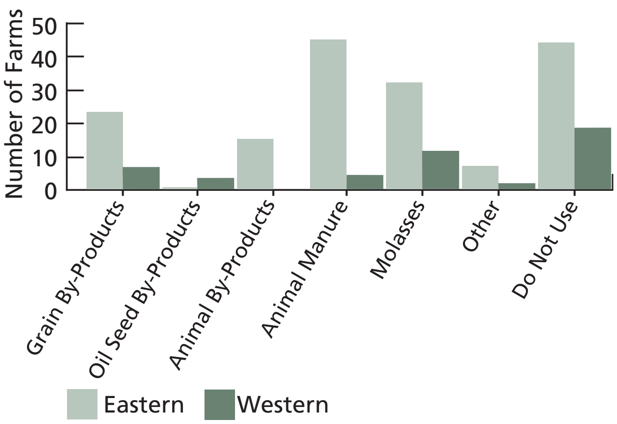


*Figure 4. Use of organic fertilizers.*

The use of molasses during pond preparation is a relatively recent phenomenon. Molasses provides a readily available source of carbon and is believed to stimulate the growth of beneficial bacteria. Typical application rates range from 50 to 100 kilograms per hectare. Grain residues such as rice bran are also widely used. Initial application rates range from 250 to 750 kiligrams per hectare.

*Molasses is an inexpensive organic fertilizer used to stimulate beneficial bacteria.*

### PREDATOR CONTROL

Filtration used during the filling stage limits the entry of predators into ponds. About 67% of the East respondents and 100% of the West used screens to filter water applied to ponds. In spite of the fine filters used in modern shrimp farming, predators may still gain entry into ponds, and additional water treatment may be required.

*The application of tea seed cake was commonly used to eliminate unwanted species in the Eastern Hemisphere.*

Organic fish toxins such as rotenone or tea seed cake, and chlorine compounds are widely used to eradicate predators. Tea seed cake was commonly used in the East (56%) while rotenone was more common in the West (26%). Application rates for tea seed cake ranged from 200 to 300 kilograms per hectare. The cakes are soaked in water overnight, and the resulting liquid is applied uniformly over pond surfaces one week before stocking so there are no residual effects on the postlarvae.

## Recommendations

One of the main reasons for difficulties in preparing ponds for shrimp culture is the selection of inferior pond sites. Mangrove areas, for example, should be avoided because their soils can be acidic, highly organic, or both. Mangrove areas also are low and drain poorly, which makes it difficult to construct or drain ponds properly for dryout. Birds, crabs, and other animals that can spread disease from one pond to another are abundant in mangroves. Moreover, tidal channels in mangroves often do not mix rapidly with sea water, increasing the likelihood of disease transmission from one farm to another.

Shrimp farms should be located outside the tidal zone. The land is higher and drains better, and sensitive coastal ecosystems do not have to be disturbed. Ponds can be constructed to drain properly, and control over the water supply and effluent discharges can be affected more easily than in the tidal zone.

Nevertheless, even in the supratidal zone, some sites have much better soils than other. Ideal soils for shrimp farms are nonacidic and contain an adequate mixture of particles to prevent high infiltration rates. The clay content can be as low as 10%, provided there is a good mixture of silt particles of various sizes. Very sandy soils and those with over 40% clay content should be avoided, if possible. Sandy soils seep badly, and heavy-clay soils do not make stable embankments and are difficult to dry and till.

Soil with exchangeable acidity can be readily remediated by liming, but potential acid-sulfate soils are more difficult to remediate. Potential acid-sulfate soils have at least 0.75% sulfur in the form of iron pyrite. When such soils are dried, the iron pyrite oxidizes to sulfuric acid and reduces pH to 3 or less.

Ease of pond preparation should be considered in pond design and construction. Ponds should have individual inlet and exit structures, and bottoms should be sloped to facilitate rapid draining. Gates also should be constructed to accommodate filtration devices.

Embankments should be wide enough to accommodate the equipment needed in pond preparation, and there should be a means of easily moving equipment into and out of ponds. Where water supplies have high concentrations of suspended solids, water should be passed through a settling basin for clarification before it enters culture ponds.

The pond preparation process depicted in Figure 5 is suggested for use by shrimp farmers worldwide. After harvest, ponds should be completely drained, dried, and tilled to enhance the oxidation of organic wastes and reduced substances, and eradicate disease agents and vectors from the previous culture cycle. Ponds with acidic soil should be treated with agricultural limestone to increase pH to 7.0 or 7.5.

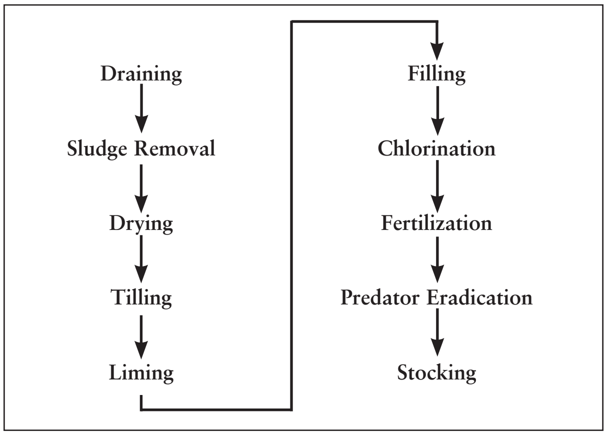


*Figure 5. Suggested pond preparation process.*

Ponds then should be filled with water that is filtered through a fine mesh screen to restrict the entry of pathogens and predators. The water can then be tested and treated to eradicate predators and disease agents that may have eluded the screen. Pond waters should be fertilized with inorganic fertilizers, organic fertilizers, or both to encourage the development of plankton blooms. Once a healthy bloom is established, postlarvae should be stocked.

The recommended pond preparation scheme should be modified as necessary for site-specific considerations. Where pond bottoms can not be completely dried, treatment of bottoms with burned lime or chlorine compounds can be an alternative means of disinfection.

It also is possible to flush wastes from pond bottoms with water. Where flushing is done, the resulting effluent should be passed through a sedimentation pond before final discharge to natural waters.

In some cases, pond bottoms may dry except in selected areas. The wet places can be treated with burned or hydrated lime at 0.25 kilogram per meter or saturated chlorine solution at 1 liter per meter to effect disinfection. Treatment of such wet spots with sodium, potassium, or calcium nitrate at 0.1 to 0.2 gram per meter also can enhance oxidation.

Sediment accumulation in ponds can create areas that will not dry between crops and are of low quality during crops. The sediment can be spread in a thin layer over pond bottoms to oxidize. It should then be put back into the area of the pond bottom from which it eroded and compacted. When sediment must be removed from ponds, it should be disposed of in a responsible manner to avoid erosion into surface water or contamination of surface or ground water with saline leachate from the shrimp pond sediment.

The survey results suggested that most shrimp farms dry or clean pond bottoms between crops, but the degree to which producers follow the recommended steps of pond preparation varies greatly. The increased application of good management practices is encouraged by the Global Aquaculture Alliance and other organizations seeking to promote responsible shrimp culture.

Particular emphasis should be given to discouraging the use of insecticides for eradicating predators and disease vectors, for this practice might lead to insecticide residues in shrimp. Other points of concern are to avoid the discharge of highly turbid water during wet pond cleaning or water containing active chlorine compounds. Pond sediment should be disposed of in an environmentally responsible manner. Fertilizers, lime, chlorine compounds, and other substances for pond preparation should be properly stored to prevent spillage.

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# FARM

# *Non-Aerated Pond Management*

GLOBAL AQUACULTURE ALLIANCE

# Non-Aerated Pond Management

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## Principles

As traditionally practiced in Asia for decades, extensive shrimp farming using tidally influenced ponds with few feed, fertilizer, and even seedstock inputs continues to be a common method of shrimp culture in China, Vietnam, Indonesia, India, the Philippines, and Bangladesh. Eastern Hemisphere farms of this type are principally located where land and labor costs are low, and inputs such as feed and postlarvae are scarce. Neither mechanized aeration, nor even routine exchange of water other than by tidal exchange is practiced at such farms.

Stocking densities are variable, but generally less than one or two postlarvae per square meter. In some instances, farms with access to financing improve yields by stocking hatchery-produced or wild-collected postlarvae and using limited amounts of feed or fertilizer. Yields from extensive farms rarely exceed 500 kilograms per hectare per year, yet this form of shrimp farming may generate as much as one-third of the world's supply of farm-raised shrimp.

*The extensive, non-aerated ponds in Latin America are typically large.*

Semi-intensive farming also continues to be a prevalent form of shrimp culture, particularly among the longer-established farms of the Western Hemisphere, but many such farms also can be found in Asia and Africa. Semi-intensive shrimp farms are characterized by the managed stocking of commercially produced postlarvae into ponds larger than 5 hectares at moderate densities, application of fertilizers and feeds, and use of water exchange to maintain water quality. Aeration, if employed, is used only on an emergency basis in case of dissolved-oxygen crises. Yields from semi-intensive farms range from 1,000 to 3,000 kilograms per hectare per crop.

*Non-aerated ponds in Asia are often small and rudimentary.*

In this report, extensive culture and semi-intensive culture are defined as shrimp production conducted in ponds without the routine mechanical aeration used in intensive shrimp ponds. Extensive and semi-intensive shrimp farms are still found in many countries of both hemispheres, but they reflect changes in stocking rates and production methods as a result of widespread problems with shrimp diseases. Traditional assumptions about extensive and semi-intensive shrimp culture methodology may no longer be entirely valid.

## Survey

Seventy-two farms responded to the non-aerated pond management portion of the Global Shrimp OP Survey. A majority (78%) of respondents to the electronic survey were semi-intensive farms from the Western Hemisphere, including eight farms in Ecuador, five in Venezuela, four in Honduras, and additional facilities in Panama, Nicaragua, Belize, Guatemala, Mexico, the United States, Peru, and Brazil.

Respondents to the electronic survey from the Eastern Hemisphere included four semi-intensive farms in India, plus individual farms in Indonesia, Madagascar, Mozambique, Malawi, and New Caledonia. In addition, the survey was translated into Vietnamese, and 32 farms were interviewed personally, with their responses subsequently incorporated into the electronic survey.

## OPERATIONAL PROFILE

Three-quarters of the respondents from both hemispheres were farms that have been in operation for more than five years. Farms in the West tended to be large, with 74% of respondents having more than 20 ponds, compared to only 7% large farms from the East.

The surface area of individual ponds in the West tended to be large. Ninety-three percent of the Western respondents had ponds of 5 hectares or more, while the ponds of 85% of the Eastern farms were smaller than 5 hectares. About 71% of the farms in the West had ponds with depths greater than 1.1 meters, whereas ponds in the East tended to be shallower. Fifty-four percent of the Eastern respondents had ponds less than 1 meter deep.

## PRODUCTION CHARACTERISTICS

Respondents from farms in the West cultured mainly *Litopenaeus vannamei* (90%) or *Litopenaeus stylirostris* (7%), with the exception of one farm that cultured the freshwater prawn *Macrobrachium rosenbergii*. Almost all the farms from the East cultured *Penaeus monodon*, with one farm that raised *L. stylirostris*.

Most farms indicated they purchased their postlarvae from commercial hatcheries (West 52%, East 88%), while the rest operated their own hatcheries. None used wild-collected postlarvae. A majority of farms in the West reported stocking postlarvae directly into growout ponds (58% as $PL_{10}$ or younger), whereas 56% of farms in the East reported stocking postlarvae first into nurseries at the farms, followed by transfer of the juveniles into growout ponds.

Limiting the number of postlarvae initially stocked is the primary means to assure crops do not grow beyond the supportable limit of semi-intensive ponds when animals grow to the intended market size. The stocking densities reported varied from less than five postlarvae per square meter (71% of respondents in the East versus 6% in the West) to five to 20 per square meter (94% of respondents from the West). In the face of frequent disease problems and consequently lower survival rates, some farms have increased stocking densities to assure sufficient shrimp at the end of the crop to obtain an economical return. Nine respondents, 13% of the total, reported stocking 21 to 30 shrimp per square meter.

*Reflecting their smaller pond sizes, Eastern farms generally harvested smaller crops than those in the Western Hemisphere.*

Reported crop yields varied greatly. About 73% of the respondents from the East indicated they harvested less than 500 kilograms per hectare per crop, while only 23% of the Western respondents reported such levels. In the West, 26% of respondents indicated production rates of 500 to 1,000 kilograms per hectare per crop, 32% reported 1,001 to 2,000 kilograms per hectare per crop, and 19% reported 2,001 to 3,000 kilograms per hectare per crop.

Ninety percent of the farms from the Western Hemisphere said the average size of their harvested shrimp was less than 20 grams, as would be expected because primarily *L. vannamei* were cultured. In the East, which cultured *P. monodon*, 81% of respondents reported harvest sizes greater than 20 grams.

Annual production during 2000 of 90% of the responding farms from the East was less than 100 metric tons. About 57% of those from the West raised similar volumes. Seventy-nine percent of the farms from the West expected increased production in 2001 versus 2000, while 53% of those in the East anticipated growth.

A majority (67%) of respondents from the West produced over two crops per year, but only 5% of Eastern farms did. Crops tended to be of shorter duration in the West – 65% of the respondents reported crops of less than 121 days, whereas 44% of the farms from the East raised their shrimp crops over the same time period.

Survival rates higher than 70% were observed in only 5% of the farms from the East and 10% of the Western farms. A majority (63% of Eastern farms, 58% of Western farms) reported survivals less than 50%. Feed-conversion ratios tended to be lower in the East than the West. Eighty-two percent of farms from the East and 74% of those from the West had ratios below 1.75.

Nearly all respondents reported that temperature, salinity, and low dissolved-oxygen concentrations significantly impacted their operations. Fewer respondents indicated impacts from pollution, sediment, and disease (Figure 1).

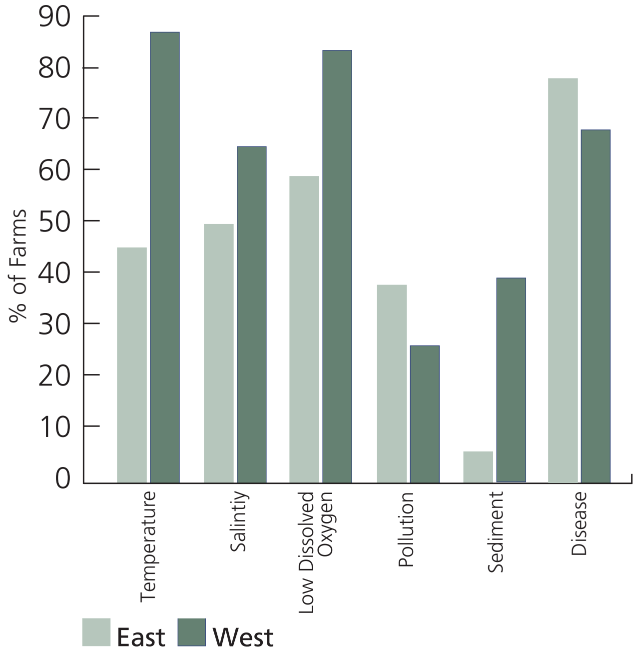


*Figure 1. Reported factors that significantly impacted farm operations.*

Respondents from the West also emphasized the importance of systematic monitoring of shrimp growth as a component of determining the biomass of shrimp in ponds, with 94% of farms performing such checks on a weekly basis. In contrast, only 37% of farms from the East monitored growth weekly, 39% checked biweekly, and 24% less often.

Aside from carefully noting the initial number of animals stocked into growout ponds, survival rates must be estimated during the course of the crop cycle. Nearly half the respondents in both hemispheres indicated the routine use of cast nets or other types of nets for estimating survival rates in ponds. The observation of feed consumption in feeding trays to estimate shrimp populations was employed by 29% of farms from the East and 42% of those from the West.

*While most Western farms monitored shrimp growth weekly, many Eastern respondents checked less frequently.*

## FARM MANAGEMENT

Farms operated without the routine use of mechanical aeration devices must rely upon other management tools to maintain a favorable culture environment throughout crop cycles. Critical environmental factors such as concentrations of dissolved oxygen and nitrogenous metabolic wastes, which are controlled by mechanical aeration in more intensive aquaculture systems, must be managed by other means in non-aerated systems.

In non-aerated systems, the dissolved-oxygen content of pond water is augmented primarily by the natural diffusion of oxygen across the pond water-air interface, aided at times by winds, plus the oxygen provided via photosynthesis by algal blooms. Management of algal blooms is considered critical in non-aerated systems, because they also consume dissolved oxygen in respiration.

Stable blooms must be maintained to avoid crashes of algae populations, which can rapidly deplete dissolved oxygen to critical concentrations. This, along with the general dilution of nitrogenous metabolites, is the principal purpose of water exchange in non-aerated systems. Some farms manage water exchange in direct proportion to the amount of feed applied, because feed is the most significant nutrient input to ponds.

In the Global Shrimp OP Survey results, significant emphasis was placed on predicting periods of low dissolved oxygen in ponds (Table 1).

Other reported means of predicting crises with low dissolved-oxygen concentrations included watching animal behavior, tracking changes in nighttime dissolved-oxygen concentrations, and monitoring wind speed.

Measures reportedly taken when ponds appeared likely to experience critically low dissolved-oxygen concentrations included those shown in Figure 2.

Other responses to incidences of low dissolved oxygen included the application of calcium carbonate, sodium nitrate, or calcium peroxide.

*Table 1. Methods for predicting low dissolved-oxygen levels in ponds.*

| Response | East | West |
|---|---|---|
| Monitor algal density using Secchi disk visibility | 63% | 82% |
| Monitor algal density using algal cell counts | 12% | 29% |
| Track trends in early-morning D.O. concentrations | 63% | 71% |
| Track trends in late-afternoon D.O. concentrations | 63% | 79% |
| Track difference between morning and afternoon D.O. concentrations | 50% | 36% |
| Monitor weather changes | 38% | 43% |

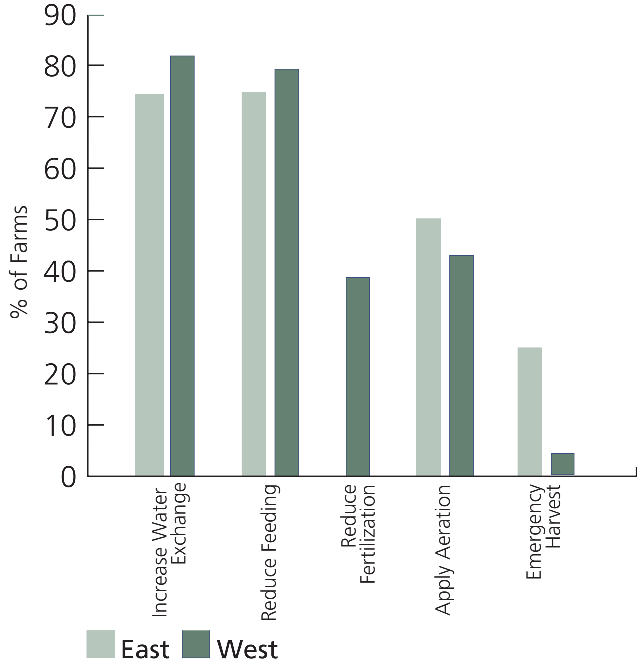


*Figure 2. Reported responses to low dissolved-oxygen levels in ponds.*

Farms in both the East and West were fairly evenly split over having considered the installation of aeration systems. The deciding factors that prevented the use of aeration among farms in the West included lower anticipated profitability (23%), higher risk (19%), lack of investment capital (26%), and lack of expertise (13%). In the East, lack of capital (37%) and lack of expertise (27%) were the main limiting factors.

## Recommendations

The results of the survey suggested that most operators of non-aerated shrimp farms are well aware of the importance of monitoring pond water quality and of the increased danger of disease infestations in ponds with high rates of water exchange. Nevertheless, not all extensive and semi-intensive producers have adopted good management practices.

*Measurements of low dissolved oxygen sparked a range of corrective actions.*

The following recommendations for non-aerated pond management can help farmers produce crops in a more responsible and efficient manner.

- Stock high-health postlarvae from reliable hatcheries.
- Do not stock postlarvae at rates that exceed the carrying capacity of ponds.
- Use conservative fertilization and feeding practices to reduce waste loads in ponds.
- Monitor dissolved-oxygen concentrations, algal abundance by Secchi disk visibility, and other water quality variables.
- Develop procedures for managing low dissolved-oxygen concentrations and other water quality imbalances.
- Reduce water exchange rates as much as practical.
- Use good pond dryout and preparation procedures, as discussed in other reports in this manual.

New methodologies likely will be introduced to allow extensive and semi-intensive farms to erect reliable defenses against external disease factors. Thus, operators of extensive and semi-intensive farms should keep up with advances in biosecurity and disease prevention, and adopt the new methodologies as applicable at their particular sites.

Shrimp producers must not assume that because production practices have been successful in the past, they will continue to be so. Large farms should invest in on-farm trials of new methodologies so the new procedures can be adopted quickly, if necessary, to deal with disease outbreaks and other problems.

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# FARM

# *Aerated Pond Management*

GLOBAL AQUACULTURE ALLIANCE

# Aerated Pond Management

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## Principles

Adequate dissolved oxygen is an essential requirement for successful aquaculture. Shrimp and most other warm-water culture species die if dissolved-oxygen concentrations fall below one milligram per liter for more than a few hours. Moreover, dissolved-oxygen concentrations below three or four milligrams per liter for several hours can stress shrimp and other culture species. Table 1 shows suggested dissolved-oxygen levels in pond water for shrimp.

*Table 1. Suggested dissolved-oxygen levels in pond water for good shrimp health (Brock and Main, 1991).*

| Dissolved Oxygen (mg/l) | Effect |
|---|---|
| 0-1.0 | Lethal |
| 1.0-1.5 | Lethal with prolonged exposure |
| 1.7-3.0 | Poor food conversion, slow growth, reduced resistance to disease if exposure continues |

Stress from insufficient dissolved oxygen leads to loss of appetite, greater susceptibility to diseases, inefficient use of feed, high mortality, and low production. Adequate dissolved-oxygen concentrations also are needed to maintain high rates of decomposition of organic matter by aerobic microorganisms, support ammonia oxidation by nitrifying bacteria, and maintain aerobic conditions at the sediment-water interface. Correct dissolved-oxygen concentrations enhance the efficiency of ponds to assimilate wastes, favor efficient feed utilization and growth by the culture species, and improve effluent quality.

Feed applications enhance aquaculture production, but aquaculture species usually convert only about 25% of the nitrogen and phosphorus and less than 10% of the organic matter applied in feed to biomass. The remainder of the nitrogen, phosphorus, and organic matter enters the pond as uneaten feed, feces, ammonia, phosphate, and carbon dioxide. Ammonia and phosphate stimulate the production of phytoplankton and increase the organic matter, as phytoplankton continually die and settle to pond bottoms as organic matter.

Aquaculture ponds typically have a high abundance of phytoplankton. During the daytime, dissolved-oxygen concentrations increase because photosynthesis produces dissolved oxygen faster than it is used in respiration (Figure 1). At night, when photosynthesis stops and respiration by the phytoplankton and other organisms in pond waters and sediment continues to consume oxygen, dissolved oxygen declines.

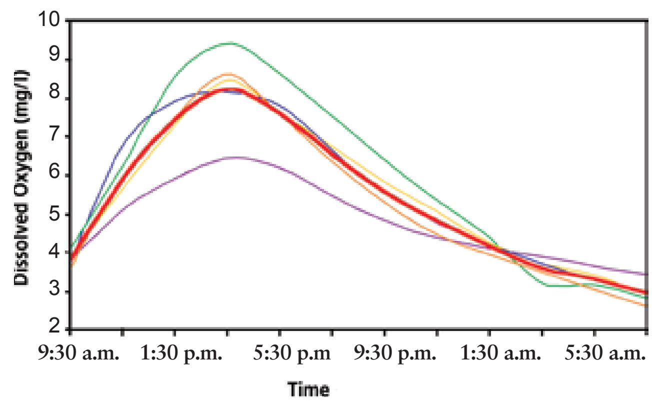



*Figure 1. Daily dissolved-oxygen fluctuations at the surface of a semi-intensive pond bottom over a 60-day production cycle of* Farfantepenaeus subtilis. *Measurements were taken every 10 days at similar time intervals. Dusk started at 5:45 p.m. and ended at 5:45 a.m. The thick line represents mean values. (Nunes, 1998).*

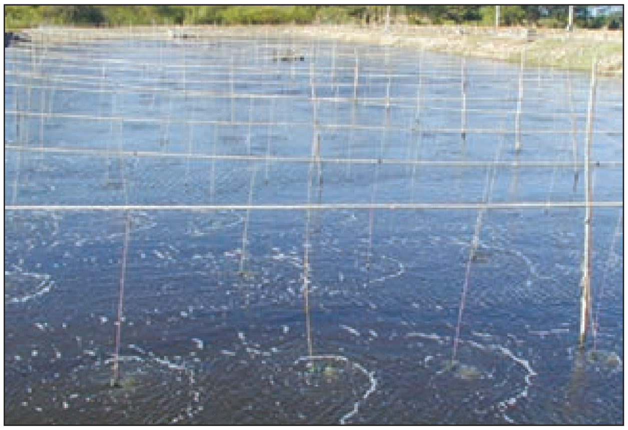
The lowest concentration of dissolved oxygen normally is found at the pond bottom, where organic matter accumulates and is decomposed by microorganisms. As production levels are increased in aquaculture ponds, more feed is applied; more nutrients and organic matter enter ponds in uneaten feed, feces, and metabolic wastes; and phytoplankton abundance increases.

The result is a wide fluctuation in dissolved oxygen with high concentrations in the afternoon and low concentrations at night. In addition, anaerobic conditions can develop at the sediment-water interface, and toxic microbial metabolites such as ammonia, nitrite, hydrogen sulfide, and certain organic compounds can enter the pond water.

Dissolved-oxygen concentrations are lower during cloudy weather than clear weather. Also, sudden phytoplankton die-offs can be followed by low dissolved oxygen levels.

Water exchange can flush out excessive phytoplankton and microbial metabolites, but this practice does not greatly improve dissolved-oxygen concentrations in ponds. Substances flushed from ponds by water exchange can pollute the natural waters into which they are disposed.

Mechanical aeration is applied to aquaculture ponds to enhance the supply of dissolved oxygen, prevent dissolved oxygen depletion at night, and circulate oxygen-



*Diffused-air systems force air through many small diffusers to pond bottoms.*

*Vertical pump sprayers consist of a motor and impeller that jets water into the air to aerate pond water.*

*Propeller-aspirator-pump aerators have a spinning impeller and a hollow shaft that draws air from the surface and breaks it into fine bubbles in the pond.*

*Paddlewheel aerators mechanically splash water into the air to cause oxygenation.*

ated water over the pond bottoms. Mechanical aeration improves pond water quality and bottom soil conditions; enhances the survival, growth, and feed efficiency of culture species; and increases production potential. It also increases the ability of ponds to assimilate wastes, thereby lessening the need for water exchange and reducing pollution loads in pond effluents.

Mechanical aeration devices for aquaculture are based on the same principles and design features as those used for waste water treatment. The most common kinds of mechanical aerators are described below.

***Diffused-air systems.*** These devices employ an air blower to force air through fine-bubble diffusers positioned on or near the pond bottom.

***Vertical pump sprayers.*** These aerators consist of a motor and impeller suspended by floats with the impeller positioned a few centimeters below the water surface. The impeller jets water into the air to effect oxygenation.

***Propeller-aspirator-pump aerators.*** These aeration units consist of a motor to which a hollow, rotating shaft enclosed in a housing has been attached. There is an air diffuser and impeller at the end of the housing. The rapidly spinning impeller lowers the pressure in the housing, and atmospheric pressure forces air into the casing. This air then exits the diffuser in fine bubbles.

***Pure oxygen contact systems.*** These devices cause contact between water and pure oxygen to effect oxygenation. These systems are rarely used in shrimp culture.

***Paddlewheel aerators.*** These aerators have paddles attached to a rotating shaft that are suspended a few centimeters into the water. As they rotate, the paddles splash water into the air to cause oxygenation. Paddlewheel aerators can be fully floating units or have their motors mounted beside ponds. Tractor-powered paddlewheel aerators are used for emergency aeration.

An extensive study of the design and performance of mechanical aerators was conducted at Auburn University in Alabama, USA, between 1985 and 1995. This research showed that paddlewheel aerators and propeller-aspirator-pump aerators were probably the most useful designs for pond aquaculture because they transferred oxygen efficiently and caused strong water circulation.

A highly efficient paddlewheel aerator design that resulted from this study has become the mainstay of channel catfish pond aeration in the United States.

*"Long-arm" paddlewheel aerators utilize multiple impellers powered by motors mounted on pond banks.*

Similar paddlewheel designs and propeller-aspirator-pump aerators have been used most widely in shrimp culture because of their low cost per unit. Table 2 shows standard aeration efficiency (SAE) values for various electric aerators used in aquaculture.

Experience suggests that each horsepower of mechanical aeration can increase the shrimp production capacity of ponds by 400 to 500 kilograms per hectare. Aeration usually is needed more at night than in daytime, but at least some aerators are operated during daytime to promote water circulation.

Aerators often are positioned to create circular water movement, but this practice can create deposits of sediment in the centers of ponds. Studies to verify the best manner of positioning aerators have not produced conclusive results.

*Table 2. Standard aeration efficiency (SAE) values for electric aerators used in aquaculture. SAE is the amount of oxygen that an aerator will transfer to water per hour under standard conditions divided by the power input to the motor. Results compiled from Boyd and Ahmad, 1987.*

| Aerator Type | Average SAE (kg $O_2$/kWh) | Range of SAE (kg O2/kWh) |
|---|---|---|
| Paddle wheel | 2.2 | 1.1-3.0 |
| Propeller-aspirator-pump | 1.6 | 1.3-1.8 |
| Vertical pump | 1.4 | 0.7-1.8 |
| Pumped sprayer | 1.3 | 0.9-1.9 |
| Diffused-air | 0.9 | 0.7-1.2 |

**Standard conditions are zero mg/l D.O., 20° C, and clean water. Values for SAE are in terms of power applied to aerator shaft (brake power).*

# Survey

The use of mechanical aeration is increasing in shrimp farming, and the goal of the Aerated Pond Management portion of the Global Shrimp OP Survey was to learn why and how shrimp farmers are applying this pond management tool. There were 140 respondents to the survey, with 20 countries represented. Since intensive shrimp farming with aeration is more common in Asia and Australia than the Americas, it should not be surprising that 84% of the respondents were from the Eastern Hemisphere.

More than half (58%) of the responding farms had five to 100 ponds. Farms with less than five ponds comprised 38% of the respondents, while only 4% had more than 100 ponds. Nearly half the farms had been in operation five years or less.

All respondents from the East reported *Penaeus monodon* as the major culture species in aerated ponds. In the West, *Litopenaeus vannamei* was the primary culture species. *Marsupenaeus japonicus* and *F. merguiensis* were each reported as major culture species by 1% of the respondents.

## CHARACTERISTICS OF AERATED PONDS

Mechanical aeration can be applied efficiently in ponds of 10 hectares or more in area, although the benefits of homogenous oxygenation, water circulation, and resuspension of organic solids are achieved more easily in smaller ponds. About 71% of the respondents said they used the traditional rectangular pond configuration. Their ponds typically ranged in area from less than 0.5 hectare (25% of respondents) to 1 ha (49%). Pond sizes from 1.1 to 5 hectares were also common (18%). Only 8% of farms had ponds larger than 5 hectares.

Square and round ponds often are promoted as best for aeration. Paddlewheel aerators can be arranged to wash out corners and cause a circular water movement. The circulation moves wastes to the center, where they settle because of weaker water currents. The centralized wastes can be avoided by shrimp, and if necessary, removed more easily between crops.

*Paddlewheel aerators can be arranged to wash out pond corners and circulate water to move wastes to the center for easier removal.*

Surprisingly, square and round ponds were used by only 20% and 3% of respondents, respectively. Also, only 3% of respondents indicated they used aeration to clean pond bottoms. Raceways and other sophisticated culture units were used for aerated pond cultured by only 3% of respondents.

Most (34%) farms in the survey operated with pond depths of 1.1 to 1.25 meters or 1.26 to 1.5 meters (28%), but 25% of the ponds exceeded 1.5 m in depth. The remainder had ponds with depths of 0.76 to 1 meter. The use of paddlewheel or propeller-aspirator aerators often is discouraged in ponds less than 0.75 meter deep because they can cause scouring of pond bottoms.

In super-intensive shrimp aquaculture systems, aeration and water circulation have been accomplished by using both electric paddlewheel aerators and propeller-aspirator-pump aerators. This combination produces water currents that maintain the bacterial floc in suspension. In the survey, 30% of respondents claimed they used intense aeration to continually resuspend organic material and create heterotrophic microbial communities to purify water and recycle protein.

## AERATION REQUIREMENTS

In shrimp-farming systems where natural oxygen replenishment is insufficient to balance respiration and prevent low dissolved-oxygen concentrations, oxygen supplementation by mechanical means is necessary. These systems may not be highly intensive. In fact, farms that operated with stocking densities between 31 and 50 shrimp per square meter comprised 33% of all respondents, while only 3% of all surveyed farms stocked more than 100 shrimp per square meter (Table 3).

Determination of the exact amount of supplemental aeration that a system requires is complex. Shrimp ponds show significant differences in their ability to assimilate wastes and consume oxygen. Shrimp farms also vary in such management inputs as water exchange, biomass, feed quality, and feed distribution – which all can influence oxygen requirements.

*Table 3. Mean shrimp-stocking densities of farms from both hemispheres that used supplemental aeration.*

| Stocking Density | Response |
|---|---|
| Less than 5 shrimp/square meter | 4% |
| 5-10 shrimp/square meter | 16% |
| 11-15 shrimp/square meter | 4% |
| 16-20 shrimp/square meter | 7% |
| 21-30 shrimp/square meter | 18% |
| 31-50 shrimp/square meter | 34% |
| 51-100 shrimp/square meter | 14% |
| More than 100 shrimp/square meter | 3% |

In addition, weather conditions differ geographically and with time of the year. In some areas, wind action can be more predominant during the dry season, which improves natural aeration processes.

Aeration requirements have been estimated empirically through experience and results obtained under commercial conditions.

The amount of aeration used per culture area is commonly expressed as either horsepower or kilowatts per hectare (1 kW = 1.34 hp or 1 hp = 0.746 kW). In this survey, typical aeration rates ranged from 3 to 5 horsepower per hectare (Table 4), although higher aeration rates were also used. The way farmers estimated their horsepower use was divided evenly between motor size (54% of respondents) and the actual motor draw power (48% of respondents).

*Table 4. Average reported aeration rates.*

| Aeration Rate | Respondents From East | Respondents From West |
|---|---|---|
| Less than 2 horsepower/hectare | 9 | 1 |
| 3-5 horsepower/hectare | 19 | 10 |
| 6-10 horsepower/hectare | 20 | 4 |
| 11-15 horsepower/hectare | 16 | 0 |
| 16-20 horsepower/hectare | 10 | 4 |
| 21-30 horsepower/hectare | 19 | 1 |
| 31-40 horsepower/hectare | 12 | 0 |
| 41-50 horsepower/hectare | 9 | 0 |
| More than 50 horsepower/hectare | 5 | 0 |

## AERATION APPLICATIONS, YIELDS

Supplemental aeration has been applied to cool pond water during daylight hours and destratify thermal gradients in the water column. Aerators are also used as mixing devices to homogenize salinity during water exchange and as circulators to resuspend organic sediment, clearing feed areas and promoting circular motion of water around pond peripheries.

Mechanical aeration is particularly necessary at night to replace oxygen consumed by plankton, benthos, and shrimp. During the night, aeration compensates oxygen loss and stabilizes dissolved-oxygen concentrations.

As an emergency tool, supplemental aeration can offset the event of sudden phytoplankton crashes or reduced solar radiation during cloudy weather. Excessive phytoplankton blooms were considered the leading cause of low-oxygen mortality in aerated ponds by 42% of the survey respondents. Prevention of oxygen kills in semi-intensive ponds came as the second primary reason for aeration use (32%).

A number of reasons for using supplemental aeration were given. An increase of shrimp yields was among the main motives (28% of respondents). Further reasons are outlined in Table 5.

A surprising 38% of those surveyed reported production of less than 3,000 kilograms per hectare per crop in aerated ponds. Almost half of all operations indicated they attained shrimp yields from 3,001 to 7,000 kilograms per hectare per cycle.

*In larger ponds, aerators are typically aligned near each other in the same direction toward prevailing winds.*

*Table 5. Primary reasons for aeration use.*

| Reasons for Aeration Use | Participation | Number of Respondents | |
|---|---|---|---|
| | | East | West |
| Mild aeration to prevent oxygen kills in semi-intensive ponds where water exchange must be avoided due to disease risks | 31.6% | 43 | 5 |
| Intense aeration to continually resuspend organic material and create heterotrophic microbial communities to purify water and recycle protein | 29.6% | 42 | 3 |
| Moderate aeration to increase yields | 28.2% | 32 | 11 |
| Water circulation | 4.6% | 6 | 1 |
| Clean pond bottom areas | 2.6% | 4 | 0 |
| Increase dissolved oxygen levels | 2.0% | 3 | 0 |
| Destratification of zero-water-exchange ponds | 0.7% | 0 | 1 |
| Reduce water exchange rates | 0.7% | 0 | 1 |

Yields of up to 10,000 kilograms per hectare represented 10% of all participating farms. Only 2% of the operations indicated they obtained higher yields. Although low stocking densities were reported by a significant number of respondents, aerated pond systems typically operate under more intensive conditions with higher shrimp biomasses than those found in non-aerated ponds.

Over 70% of the respondents harvested shrimp with body weights between 16 and 30 grams. The majority of respondents attained at least two crops per year, with the crops lasting an average of 111 and 130 days. Most (66%) farmers reported achieving feed-conversion ratios between 1.26 and 1.75. Shrimp survival rates during grow-out ranged between 51 and 70%.

## POSITIONING

Based on the survey, aerator positioning appeared to relate to the configuration and area of the ponds. In small rectangular, square, or round ponds, aerators were positioned around outside pond perimeters to create a clean feeding area (44% of the respondents), between the outside edges and pond centers to promote circular currents (20%), or near corners to prevent accumulation of wastes (16%). In larger rectangular ponds, 14% of respondents said they pointed aerators in the same direction toward prevailing winds, aligned near each other and 45 to 90 degrees from pond walls.

Most respondents apparently were aware of the fact that when several aerators are put in a pond, it is best to mount them so they do not work against each other in producing currents. In a few (2% of the respondents) cases, farmers placed aerators in water distribution channels to increase dissolved-oxygen levels before supplying new water to ponds.

## AERATOR OPERATION

One of the greatest restrictions to more widespread use of aeration seems to be operational costs, particularly power expenses. Interestingly, aeration has recently become quite popular in countries like Brazil, where power derived from hydroelectric plants is common in rural areas and relatively inexpensive compared to other power sources. In Brazil, it is estimated that electricity generated by diesel fuel is at least three times more expensive per kilowatt hour than electricity obtained from electrical utilities.

Some 48% of respondents used electricity derived from utilities, and 19% generated power on site. Some aerators, such as the long-arm paddlewheels, are driven using an extended shaft with a small gasoline motor and speed-reduction mechanism mounted on a pond wall. Power sources from gas or diesel motors represented 31% of the responses, while tractor drive was only 1%.

Shrimp farms that rely on electricity as their main power source should rent or purchase mobile diesel or gasoline generators to serve as backup power supplies. Power failure can lead to a rapid drop in dissolved-oxygen concentrations, especially under intensive conditions and in the more advanced stages of growout. A high shrimp biomass can cause a dissolved oxygen depletion within a few hours of aerator failure.

More than half (55%) the surveyed farms indicated the use of a complete backup power supply for emergencies, followed by 32% with partial backup and 13% with no backup equipment. This reflected the finding that 10% of the respondents indicated power outage was one of the leading causes of low-oxygen shrimp mortality in ponds.

Forty-three percent of the respondents indicated their power costs did not exceed U.S. $0.07 per kilowatt hour. The costs of diesel fuel ranged from U.S. $0.20 to $0.30 per liter for 17% of the survey respondents to $0.31 to 0.40 per liter for 14%.

*Some farmers run aerators in water channels to raise dissolved-oxygen levels before adding water to ponds.*

## AERATOR PURCHASING, MAINTENANCE

The quality of materials, motor, gear box, and bearings, and proof of performance should be taken into consideration when purchasing aerators. Paddlewheel design, for example, can affect oxygenation efficiency, as well as power consumption. Materials with low resistance to corrosion are likely to fail frequently. This leads to higher maintenance costs and a greater risk of shrimp mortality, especially under more intensive systems.

Those responding to the survey seemed to be generally aware of quality and performance issues. When purchasing aeration equipment, respondents indicated the cost of the equipment and credit availability were low priorities (Table 6). Aerator efficiency, reliability, and ease of maintenance were considered the three most important deciding factors. Twenty-two percent of farms called aerator failure one of the top causes of shrimp mortality in their ponds.

*Table 6. Top concerns for aerator purchases. Values refer to the number of responses given and their relative participation in each priority level. Higher values indicate higher priority.*

| Concern | Order of Priority | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1st | | 2nd | | 3rd | | 4th | | 5th | |
| Aerator cost | 22 | 16% | 35 | 26% | 37 | 28% | 34 | 26% | 5 | 4% |
| Aerator reliability | 19 | 14% | 45 | 33% | 30 | 22% | 34 | 26% | 3 | 2% |
| Aerator efficiency | 82 | 59% | 32 | 24% | 13 | 10% | 10 | 8% | 1 | 1% |
| Ease of maintenance | 12 | 9% | 23 | 17% | 51 | 38% | 40 | 30% | 9 | 7% |
| Credit availability | 3 | 2% | 0 | 0% | 3 | 2% | 13 | 10% | 107 | 86% |

Although successful aeration systems are available, several questions remain to be explored. The mechanisms involving aeration versus water circulation in shrimp ponds were considered the top priority area for research by surveyed farms. They were followed by studies on improved gas exchange efficiency, variable operating speed (day versus night), automatic aerator control by dissolved-oxygen sensors, and alternative energy sources.

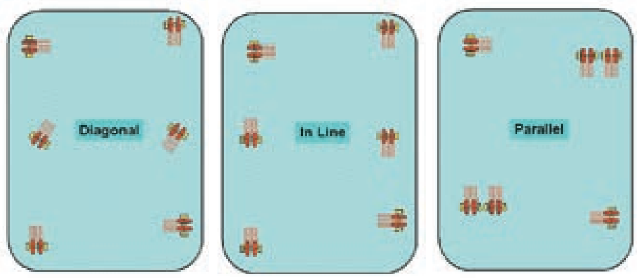
As more shrimp farmers learn the benefits of pond aeration, better management strategies and less-expensive technologies should evolve to make aeration a more widely accessible tool in shrimp aquaculture.

# Recommendations

Mechanical aeration is a powerful tool for increasing the capacity of shrimp ponds while maintaining good water quality and sediment condition. Aeration is particularly useful because it allows greater production without high water exchange rates. Therefore, shrimp producers who desire to harvest more than 1,500 kilograms per hectare per crop should invest in mechanical aeration.

Experience suggests that electric paddlewheel aerators or propeller-aspiration-pump aerators are most useful in shrimp ponds. These types of aeration transfer oxygen efficiently and promote good water circulation. However, both types can cause erosion of pond bottoms and embankments.

Aerators positioned too close to pond walls can cause erosion unless embankments are sloped, compacted properly and reinforced with grass, liners, or stone. Pond bottoms in front of aerators can be reinforced with stone to prevent scouring. Following are suggested aerator positions for efficient aeration.




*Three aerator arrangement strategies aimed at promoting water circulation and centralization of waste material in rectangular ponds. (Peterson et al., 2001.)*

Aeration can be initiated in ponds before stocking postlarvae or after growout begins. It is important to examine pond bottoms soon after harvest to determine where sediment accumulated during the previous crop. This facilitates the identification of areas where circulation was poor, so aerators can be repositioned to enhance circulation.

Once aerators are installed, electrical service panels should be ready for activation with all aerial and submerged electrical cables connected and in place.

*This growout pond is ready to be filled with water. Note the electrical cables connected to a control panel, with poles and aerators properly positioned.*

Aerators are usually anchored by poles made of metal, PVC, or wood. The poles can be placed in holes drilled into the pond bottom or fixed on concrete bases on pond floors. Once aerators have been positioned, relocation should be avoided during growout. Pole removal and movement of aerators can stir up organic material and toxic substances on pond bottoms.

Aerator arrangement is an important consideration. It affects water circulation patterns and determines the most oxygenated zones and areas of sediment deposition in ponds. Shrimp tend to avoid pond areas with low dissolved-oxygen concentrations or where there is build-up of ammonia, hydrogen sulfide, or methane.

The timing of aerator operation is determined by pond water quality and the amount of shrimp biomass. Aerators usually are turned on overnight for eight to 12 hours. In ponds with feeding trays, aerators usually should not be turned off during or after feed distribution, but should be switched off during broadcast feeding.

Under more intensive conditions, aerators can be operated alternatively over a 24-hour period. For example, half the aerators could be used in the daytime and all used at night. Also, the number of aerators in operation can be increased as shrimp biomass grows.

As dissolved-oxygen saturation is approached, the rate of oxygen transfer declines logarithmically. When saturation is attained, aerators stop transferring oxygen from air to water. The operation of aerators during daylight hours, when photosynthetic activity is high, results in the loss of oxygen from supersaturated pond water and an increase in power costs.

Farm personnel should be trained in proper safety procedures regarding aerators, especially turning off electric power before working in the vicinity. Aerator maintenance should be carried out between production cycles, as this can help avoid aerator failures during growout (Table 7). Maintenance should involve the checking, adjustment, and replacement, if needed, of electrical and mechanical components. This includes changing the reducer oil, checking fuses in the switch panel, and washing off dead algae attached to aerators.

*Table 7. Suggested aerator maintenance program.*

| Frequency | Type of Maintenance |
|---|---|
| After shrimp harvest | Change oil in the reducer and lubricate all movable parts |
| | Apply anticorrosive coating on reducer and motor |
| | Wash motor housing, floating platforms, paddlewheels, and anchor poles |
| | Check the integrity of electrical cables, rotor shaft, rubber of roller bearings, movable joints, rotors, and paddlewheels |
| Weekly | Inspect fuses, relays, circuit breakers, and switches |
| Annually | Complete repairs of reducer, motor, and switch panel |

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# FARM

# *Pond Water Quality*

GLOBAL AQUACULTURE ALLIANCE

# Pond Water Quality

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## Principles

Water quality is universally regarded as one of the most important aspects of shrimp culture, because poor water quality stresses the animals and can result in slow growth, disease, and even death. Water quality in shrimp ponds is affected by climatic conditions, characteristics of source water and pond soil, and intentional inputs of fertilizers, feeds, and other materials.

The optimal ranges and critical thresholds of water important quality variables have been defined intuitively and experimentally. Shrimp are cultured under a wide range of environmental conditions in production systems that vary from extensive, low-input farms to intensive facilities with high input levels.

The amount of attention given to water quality management increases as production intensity increases. Nevertheless, pond water quality and the practices used to manage it are some of the most dynamic and least understood aspects of shrimp culture. Water quality management is often based more on managerial opinion than scientific information.

Over the years, shrimp culture technologies evolved from open to closed systems, and the need for monitoring water quality increased accordingly. Zero-exchange or closed-system technology, which can be practiced under intensive or hyperintensive regimes, is revolutionizing the industry, but requires a better understanding of the culture environment and more effective water quality management.

## Survey

The thrust of this section of the Global Shrimp OP Survey was to document the status of water quality monitoring on farms, record producer opinions about the factors that influence water quality, and determine which management tools were being used to control water quality.

There were 209 respondents for pond water quality, with 176 from 12 countries in the Eastern Hemisphere and 33 from 17 countries in the Western Hemisphere. The survey was designed with questionnaires in electronic format. However, in Thailand and Vietnam, direct interviews of farmers were conducted with the same set of questions as in the electronic survey.

*The majority of survey respondents were from the Eastern Hemisphere, where many smaller farms have a limited capacity to monitor and actively manage pond water quality.*

Many farmers in the East are small-scale operators who are poorly equipped to monitor water quality on a regular basis, while their Western counterparts are dominated by larger corporate farms with systematic monitoring capability. To make up for limited instrumental monitoring, Eastern farmers are generally more vigilant in observing pond conditions and managing their ponds.

*Water for shrimp ponds can be pumped from a variety of sources.*

## SOURCE WATER

Water for marine shrimp culture can be obtained from the open sea, embayments, estuaries, tidal rivers, saline ground water, and fresh water mixed with brine or salt. As shown in Figure 1, More than 60% of farmers filled their ponds from estuaries or tidal rivers. The tidal range was reported as one to two meters in the East and zero to four meters in the West.

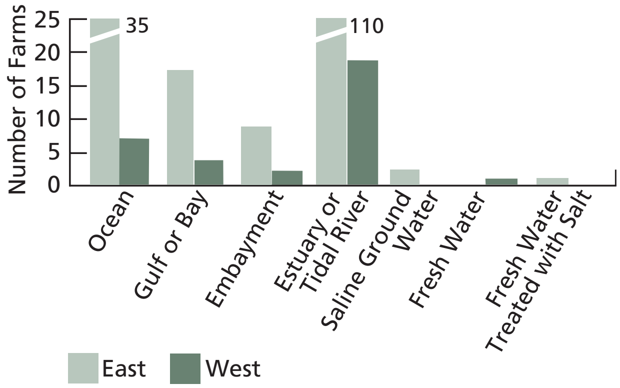



*Figure 1. Source of pond water.*

As estuaries and tidal rivers receive sediment from erosion, runoff, and resuspension, most source water was reported to be moderately turbid. In tidal rivers, turbidity from suspended soil particles varies seasonally and is higher during the rainy season. To reduce the turbidity in source water, over 80% of farmers in both hemispheres stored water in reservoirs or sediment ponds (Figure 2). Only one-third of the farmers filled ponds directly with source water.

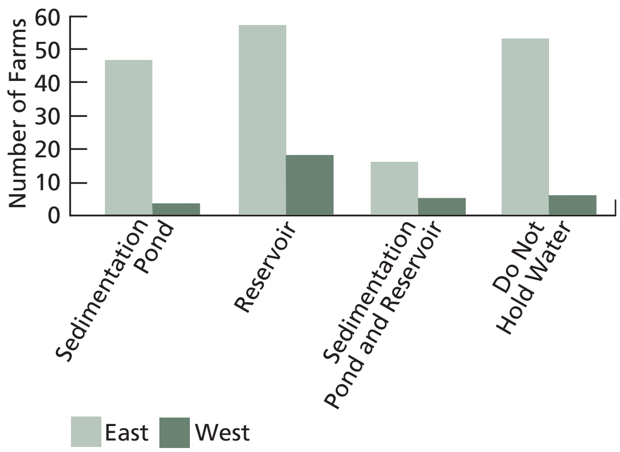



*Figure 2. Treatment of turbid source water.*

Besides allowing suspended particles to settle, reservoirs function as water reconditioning systems where microbial processes degrade organic matter and generally improve the quality of water for shrimp culture. They also can be used to facilitate the chemical treatment of incoming water. In closed systems with the capability to reuse water, reservoirs serve as water storage for periodic on-farm water exchange.

*Pumps deliver highly turbid water. Many Eastern farmers suspected their source water was moderately contaminated by wastes.*

The source water for shrimp ponds often is subject to external pollution from land runoff or municipal and industrial effluents. Over 60% of the farmers in the East suspected their source water was moderately contaminated by pollutants from domestic, agriculture, and industrial wastes. Agricultural pollution was regarded as the most common problem. In comparison, most farmers in the West did not consider their source water polluted.

## WATER QUALITY VARIABLES

A wide range of water quality variables was included in the survey. Salinity, dissolved oxygen, pH, ammonia, and total alkalinity were monitored widely on a regular basis by over half the farmers in both hemispheres (Figure 3). Water temperature and Secchi disk transparency were measured by most Western farmers, but only received moderate attention in the East.

***Water temperature.*** Water temperature in ponds can fluctuate daily and seasonally between 15 and 35 degrees C. In this survey, the minimum daily temperature ranged from 21 to 25 degrees during the cool season. The maximum daily temperature varied from 31 to 35 degrees in the warm season for the majority of ponds in both hemispheres.

Although the culture species vary, with *Penaeus monodon* in the East and *Litopenaeus vannamei* in the West, shrimp are cultured year round in both dry and rainy seasons. However, farmers usually avoid stocking shrimp during cold spells or heavy rains. For instance, in Thailand, little activity occurs from December to February, when the water temperature can fall to 22 degrees C.

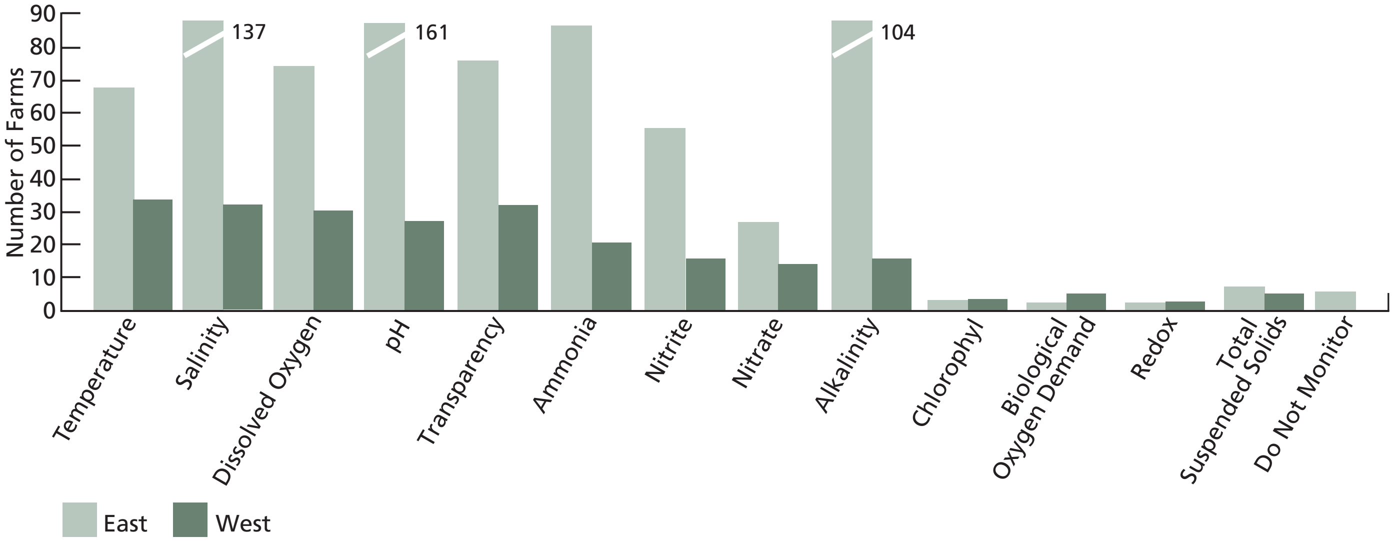



*Figure 3. Routinely monitored water quality parameters.*

*Salinity, a common water quality variable, reflected both regional and seasonal variations.*

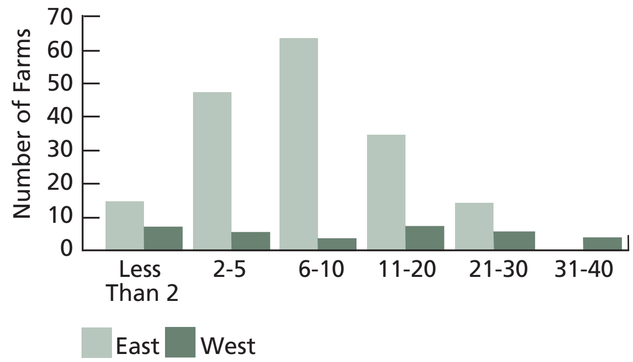
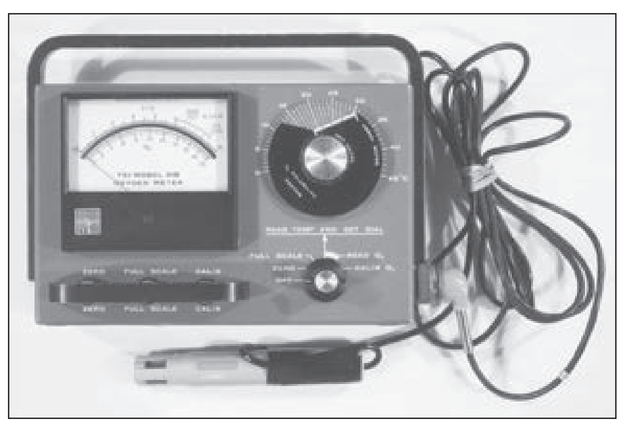



*Figure 4. Minimum salinity (ppt) of pond water.*

***Salinity.*** The salinity in shrimp ponds was one of the most commonly monitored water quality variables. Globally, it was reported to vary from near that of fresh water (below two parts per thousand) to above 40 parts per thousand (Figure 4). Like temperature, salinity also exhibited marked seasonal variations, with minimum salinity at two to 20 parts per thousand in the wet season and maximum salinity of 20 to 40 parts per thousand in the dry season. In the West, the maximum salinity tended to range higher (30 to 50 parts per thousand) than in the East (20 to 40 parts per thousand).

In recent years, many shrimp ponds in the East have been operated as closed systems with little water exchange during growout. This often results in high salinity during the dry season. In some instances, fresh water is added to ponds to prevent exceedingly high salinity.



*Dissolved oxygen meter.*

***Dissolved-oxygen concentration.*** Dissolved-oxygen (DO) concentration is the most dynamic variable in pond water, but is critical to shrimp survival. More than 50% of respondents in the East reported that early morning DO concentration usually was above two milligrams per liter. In contrast, the lowest early-morning DO concentration in the West was reported below two milligrams per liter (Figure 5).

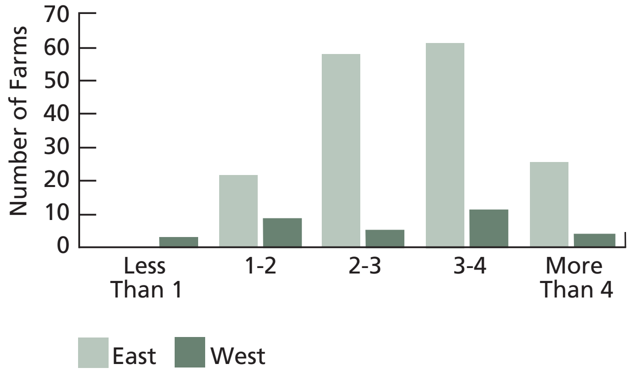



*Figure 5. Minimum dissolved-oxygen concentration (mg/L) in pond water.*

*As measured by pH meters and other methods, pH values were generally higher in the Western Hemisphere.*

***Total alkalinity, pH.*** Sea water normally contains total alkalinity greater than 100 milligrams $CaCO_3$ per liter. However, as most shrimp farms are supplied with water from estuaries or tidal rivers, the total alkalinity in these source waters can be lower than that of full-strength sea water.

In the East, the most typical alkalinity in source water and desired level for shrimp ponds ranged from 76 to 120 milligrams per liter (Figure 6), but fluctuated seasonally – lower in the rainy season and higher during dry seasons. In the West, most source water and ponds contained greater than 100 milligrams per liter total alkalinity. The pH range in most pond water was 7 to 9, and higher pH (8 to 9) was more prevalent in the West than the East.

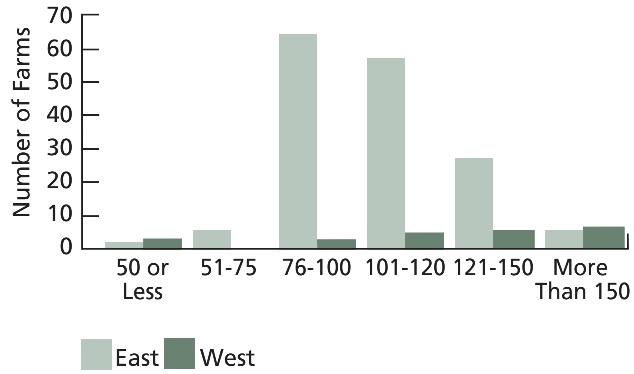



*Figure 6. Common and preferred alkalinity (ppm) in pond water.*

***Nutrients and algal growth.*** Monitored nutrients listed in the survey included nitrogen, phosphate, silicate, and iron (Figure 7). Most (76%) farmers from the East did not monitor nutrients. Only 17% measured nitrogen and 7% measured phosphorus. In contrast, more than 50% of farmers from the West monitored nitrogen and phosphate on a weekly basis, and some measured silicate (20%). The most common concentration of nitrogen was between two and four milligrams per liter, and phosphorus concentration usually was between 0.1 and 0.3 milligrams per liter.

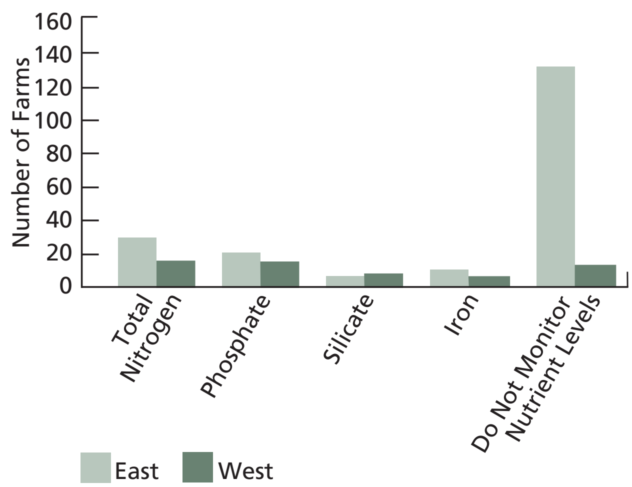



*Figure 7. Nutrient parameters commonly monitored by farmers.*

Nutrient enrichment is a common occurrence in shrimp ponds that stimulates the growth of phytoplankton and macrophytes enough to cause management problems. More than half of the responding farmers from both hemispheres checked phytoplankton and zooplankton abundance in their ponds. They said they did this to maintain "good pond color" and prevent excessive growth of undesirable species such as toxic blue-green algae and dinoflagellates. Nuisance growth of filamentous algae was also a common problem in the East.

*Dense phytoplankton blooms are often dominated by undesirable blue-green algae.*

## WATER QUALITY MANAGEMENT

Traditionally, the water quality in shrimp ponds was maintained largely by water exchange during daily tidal cycles. However, this practice has been markedly reduced because of unpredictable water quality and the risk of pathogens in external source water (Figure 8).

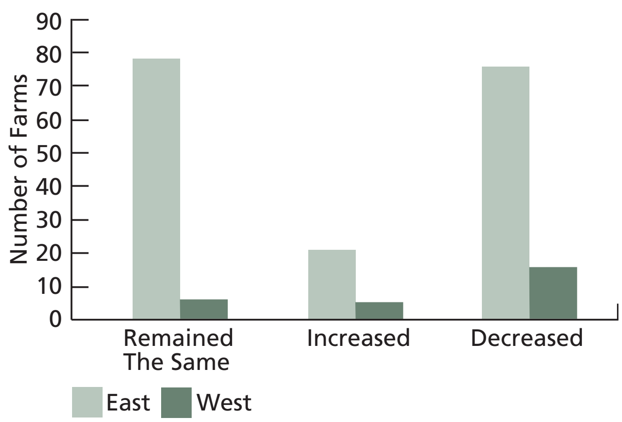



*Figure 8. Recent changes in water exchange rates.*

Most farmers have adopted a strategy of less water exchange, especially in areas where there are many intensive shrimp farms. Nearly 50% of farmers from the East exchanged less than 2% of pond volume daily throughout the whole growout cycle. But more Western farmers practiced a higher water exchange rate of 6 to 10% (Figure 9).

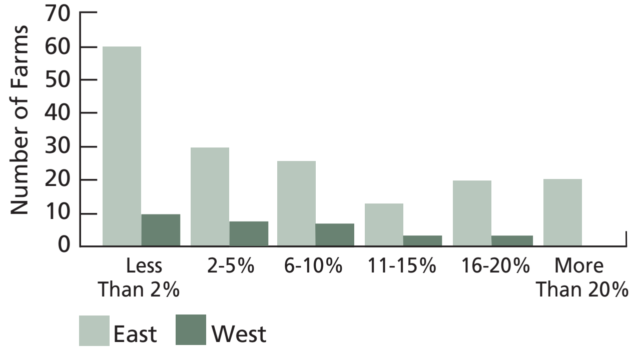



*Figure 9. Daily water exchange rate.*

Efforts to improve water quality and mitigate disease problem in ponds included the use of various probiotics by 58% of the farmers from the East. However, in the West, only 20% of farmers reported probiotics use.

Most (68%) farmers used one-half to one metric ton of ordinary agriculture limestone or dolomitic agricultural limestone to boost alkalinity when necessary (Figure 10). Less than 50% of farmers treated their ponds with lime (calcium oxide or calcium hydroxide) or other acid-neutralizing products to increase alkalinity or pH. In Thailand, organic material such as sucrose and molasses are commonly used to lower pH when excessive phytoplankton blooms occur in ponds.

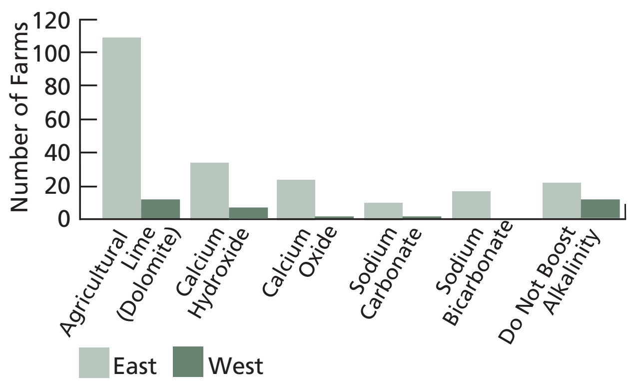
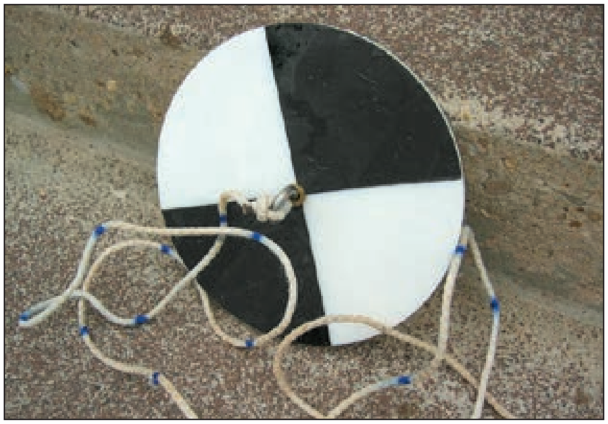



*Figure 10. Chemicals used to boost alkalinity in pond water.*

Generally, the minimum DO concentration is higher and more stable in aerated ponds than extensive ponds with low input. Aeration is used more commonly in the East, but the practice is increasing in the West.

Shrimp farmers are aware of the importance of water quality and the majority of farmers monitor water quality in their ponds at various frequencies. Water quality variables most often measured include temperature, dissolved oxygen, Secchi disk visibility, salinity, pH, and total alkalinity. Biological variables such as abundance of phytoplankton, zooplankton and bacteria were monitored less frequently.



*Secchi disks are a practical tool for evaluating water turbidity.*

The two most significant factors that determine pond water quality are the characteristics of source water and bottom soil. Turbidity in source water reduces light for phytoplankton growth and causes heavy sediment deposition on pond bottoms.

This survey showed that sediment load ranged from moderate to heavy in most estuarine environments and especially in Ecuador, Honduras, and Nicaragua. For Vietnamese farmers in the Mekong Delta, muddy water was a severe problem. As much as 50 centimeters of sediment can accumulate in pond bottoms each year. To mitigate turbidity problems, source waters are often passed through sedimentation ponds or reservoirs. However, many small-scale farmers cannot afford to follow this protocol.

*Sedimentation is a problem at some large farms in Latin America.*

## Recommendations

This survey showed that farmers are aware of water quality monitoring and management issues. However, it appears most farmers have a limited understanding of water quality principles and methods.

The following recommendations for water quality management are based on the findings of this survey and other experiences with shrimp farmers.

- Less water exchange should be encouraged.
- Farmers should regularly monitor water quality in ponds.
- Shrimp producer associtions, extension agencies, and other support groups should educate shrimp farmers on water quality monitoring and the use of monitoring data in pond management.
- Ongoing research should more fully evaluate the varied water management practices used by shrimp producers and develop guidelines for maintaining water quality in ponds.

Probably the most important universal trend in shrimp pond water management is the decreasing rate of water exchange. By reducing water exchange, farmers can avoid the introduction of low-quality water during the culture period and prevent disease vectors from entering ponds.

Ironically, many environmentalists think aquaculture is a major cause of water pollution. However, other human activities often pollute the water before it is used by shrimp farmers. Polluted water supplies are a major problem in shrimp culture.

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# FARM

# *Feed Management*

GLOBAL AQUACULTURE ALLIANCE

# Feed Management

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## Principles

The development of compound aquafeeds has been a major factor in the successful expansion of shrimp farming, and effective feed management is crucial to maintain the industry's financial and environmental viability. Good feed managers supply the best quality artificial feed in the required amounts and at the right times and places. This requires experience, knowledge of shrimp behavior, and a continuous pond-sampling program that provides accurate and timely data on pond environmental parameters, and shrimp biomass, size distribution, and individual mean size.

Aquafeed management is a sequential process that is only as strong as its weakest link. It includes feed selection, handling, storage, application, and adjustments as necessary. Feeding strategies should follow the natural feeding habits of the shrimp species cultured and respond to its molt cycle to maximize feed utilization and reduce feed waste. The importance of proper feed management cannot be overemphasized. If not managed properly, even the best shrimp feed will be at best an expensive fertilizer.

*Shrimp feed must supply nutrition in a reasonably water-stable form that will also attract animals to consume it.*

### FEED CHARACTERISTICS

While farm personnel typically develop their own feed quality requirements, several accepted quality criteria are used to evaluate fprmulated shrimp diets. These include pellet size, uniformity, physical integrity, density, humidity, protein content, lipid content, water stability, attractability, and smell.

The feed selected must fulfill the known nutritional requirements of the targeted species. It must be fresh and free of mycotoxins and pesticides, and have low pollution potential. The feed should have attractants and/or natural foods to improve detection and palatability, and stimulate rapid consumption. Attractants can improve feed perception and reduce feeding response times as much as 50% when compared to feeds without attractants.

*Many bigger farms distribute large quantities of feed from boats or vehicles with mechanical blowers.*

### FEED DISTRIBUTION

There are several ways to apply formulated feeds to shrimp production systems. In larger ponds, aquafeeds are applied by manual broadcasting from boats, some of which have gasoline engines, or mechanically by blowers mounted on boats or vehicles on pond levees. Even crop-dusting airplanes have been used to distribute feed to very large ponds.

In small, intensive ponds, tanks, and raceways, automatic feeders with timing mechanisms can be used. Automatic feeders are a useful alternative to manual feed broadcasting in smaller systems, but should not replace regular observations by trained personnel. At many farms in several countries, all feed is applied exclusively using feeding trays.

As production cycles progress, pond managers must be aware that shrimp react to changing microhabitat variability in the pond, both in space and time. Animals avoid areas where anaerobic sediments accumulate and noxious compounds such as hydrogen sulfide are present. These areas include internal drainage canals and areas close to the drainage structures. This is more relevant toward the end of the growout cycle, when considerable sludge can accumulate.

Shrimp move to deeper areas within ponds during the day to avoid light. Therefore, very shallow areas or those with anaerobic sediments should not receive feed during daylight hours, because it is unlikely shrimp will consume it. However, it is also important to consider that shrimp distribution in ponds is generally not uniform, and that several factors influence how animals distribute themselves.

### ADJUSTING FEED QUANTITY

Feed amounts are still widely established based on a set schedule that depends on animal weight and estimated biomass/survival in the pond. Feeding based on tables is also widely practiced. These tables can vary by species, geographic area, age of animals, target size, culture intensity, water temperature, dissolved-oxygen level, feed attractability, water stability, frequency and times of feeding, and other factors.

Daily rations are calculated based on estimates of density, mean individual animal weight, survival, and body weight percentage to feed. Each farm can develop its own in-house survival and feeding tables over time, but should also properly consider the natural feeding habits of shrimp and their physiological states.

*Feeding trays can be variably used to both apply feed and monitor feed consumption.*

When using feed trays to adjust feed rations, many criteria interpret the amount of feed left and what action to take. In addition, feeding adjustments are also made based on changing pond water conditions determined after morning and afternoon water quality monitoring. Water temperature, dissolved-oxygen concentration, and pH are the most relevant parameters in tables.

The reliability of feed trays for estimating food consumption is still questioned by some. Shrimp may use trays as a refuge from reduced pond sediments. The presence of crabs can keep shrimp away from trays and result in underestimation of feed consumption.

The main argument against using feeding tables is that it is very difficult to continuously and accurately estimate the survival of animals in ponds. Therefore, at many farms, feed manufacturers' guidelines and tables are followed when feeding for the first time, then daily rations are adjusted using feed trays.

## Survey

One hundred seventy-nine respondents participated in the Feed Management section of the Global Shrimp OP Survey. About 83% of the responsents were from the Eastern Hemisphere, with 67 from Thailand, 33 from Vietnam, and 15 from India. In the Western Hemisphere, there were six responses from Ecuador, five each from Honduras and Venezuela, and additional responses from seven other countries. Not all respondents answered every survey question.

### PROTEIN LEVEL

Protein content is probably the first characteristic of feed examined by shrimp farmers, and many believe that "more is better," which is not necessarily the most cost-effective and profitable approach. Using feed that meets shrimp's requirements for amino acids is absolutely critical, because the acids can be major limiting nutrients for growth.

However, protein is one of the most expensive components of shrimp diets. It is desirable to minimize the protein levels in diets but only without compromising shrimp production and profitability.


*Feed must contain sufficient protein for good shrimp growth and do so at a reasonable price.*

In the East, about 86% of the respondents used feeds with protein levels between 31 and 45%. In the West, about 84% of respondents used feeds with protein levels between 21 and 35% (Figure 1). These values reflected the prevalent species cultured when the survey took place. Black tiger shrimp, which require higher-protein feeds, were the prevailing species in the East. Pacific white shrimp, with lower protein requirements, were the prevalent species in the West.

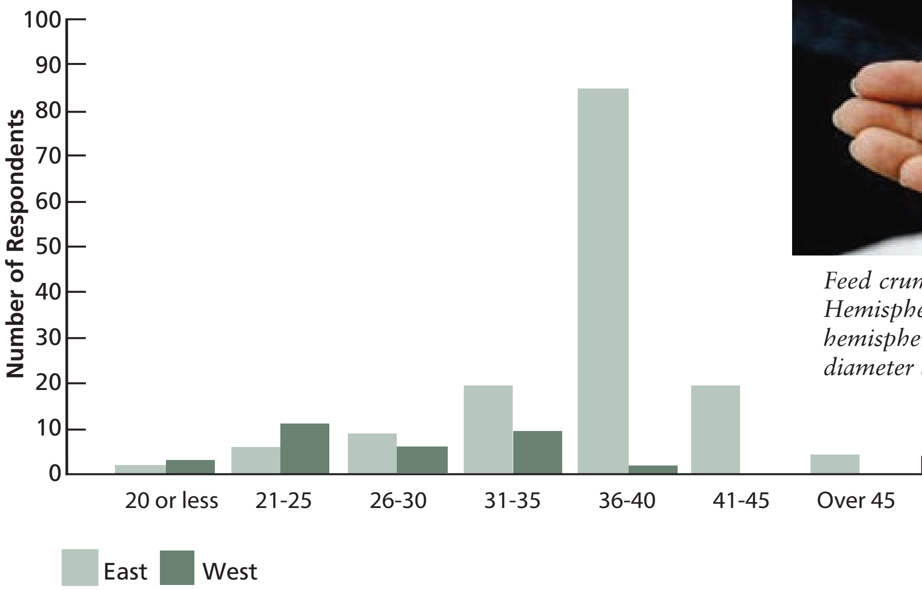



*Figure 1. Protein content (%) in primary growout feed.*

*Feed crumbles were widely used in the Eastern Hemisphere. Most respondents from both hemispheres used feed pellets of 2-millimeter diameter and greater.*

## WATER STABILITY

Hydrostability is the ability of submerged feed pellets to retain their physical integrity and nutrients until consumed by shrimp. This is a very important characteristic, because pellets must be sufficiently stable to prevent deterioration and nutrient loss, but also release enough chemoattractants to promote rapid consumption and minimize waste. About 81% of the survey respondents indicated their feeds had hydrostability over 60 minutes (Figure 2).

Crumbles are crushed feed pellets made especially for smaller shrimp to facilitate handling, consumption, and more efficient feed utilization. The pellets are first crushed into smaller pieces, then sieved to separate different fractions.

In the Eastern Hemisphere, all respondents used crumbles, with 88% using two to five crumble sizes. In the West, 17% of respondents did not use crumbles. Among those who did, 72% used only one to three sizes.

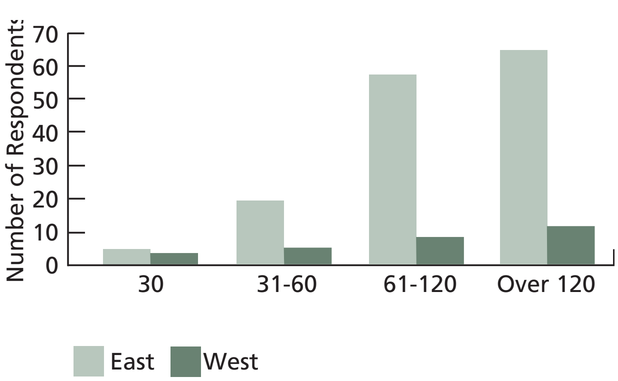



*Figure 2. Estimated water stability (minutes) of primary growout feed after immersion in water.*

When feeding, shrimp typically grab pellets and move away from other shrimp to consume them, so pellet size must be appropriate to shrimp size. In the East, about 27% of respondents used growout feed pellets under 2 millimeters in diameter, while in the West, only 10% of respondents did so. In the East, about 75% of respondents used pellet diameters of 2.0 to 2.1 millimeters. About 76% of Western respondents used feed pellets from 2.0 to 2.5 millimeters in diameter.

## FEED APPLICATION BEFORE STOCKING

A practice common in some areas is to add commercial feed to ponds at rates of 5 to 20 kiligrams per hectare a few days before stocking to further stimulate benthic production. It is also believed that this practice can help young shrimp get used to eating commercial aquafeeds sooner.

Sometimes small amounts of pulverized growout feed are added to postlarvae tanks for several days before transfer to farm ponds. The majority (88%) of survey participants did not apply feed before stocking shrimp postlarvae.

## DAILY FEEDING

In general, healthy shrimp feed continuously, day and night, so it is important that adequate amounts of feed are available. This is particularly important at higher shrimp densities and with larger animals, in ponds where the carrying capacity of natural productivity has been surpassed. Most respondents (89%) applied feed to stocked ponds every day.

Available information indicates that most cultured shrimp species congregate rather than disperse in production ponds, so it is important to distribute feed appropriately to maximize detection and consumption. Most survey respondents (85%) distributed feed by manual broadcasting from boats (54%) or pond levees (31%). Five respondents used mechanical broadcasting from levees, and 19 used feeding trays (Figure 3).

Most (83%) respondents required one to four man-hours per hectare daily for feed application, while 16% of the participants needed five to eight man-hours per hectare per day. Two Western Hemisphere respondents indicated they required nine or more hours per hectare.

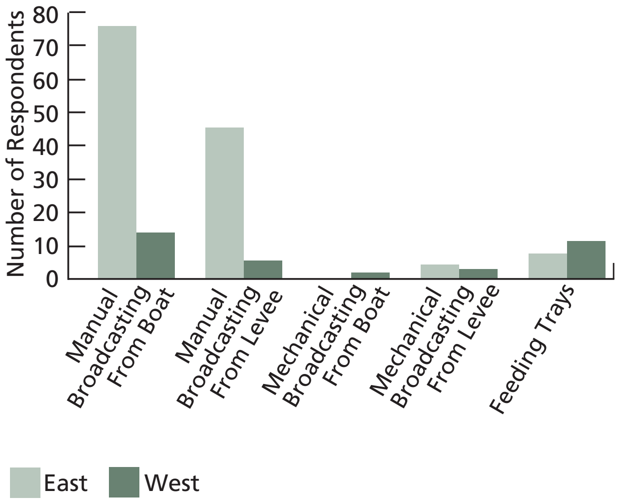



*Figure 3. Primary feed distribution method.*

## FEEDING FREQUENCY

How often to apply feed is an important decision that each farm has to evaluate based on experience; season; changing environmental conditions; shrimp species, age, and size; stocking density; production system; stress; available resources; and other considerations. In the Eastern Hemisphere, about 79% of respondents applied feed four or five times per day. In the West, 22% of respondents fed only once daily, and 59% fed two or three times a day (Figure 4).

The optimal number of times to feed remains an unresolved subject that is largely dependent on the experience of farm managers and their available resources. Increasing the frequency of feeding generally produces immediate benefits, including reduced nutrient and feed loss, and increased growth and feed utilization. About 71% of the Eastern respondents increased the number of daily feedings as the production cycle progressed, while about 63% of the Western participants did not.

At many farms, feed is applied only during the day due to personnel considerations and convenience. Feeding during the night, however, can become more important as the production cycle progresses and the availability of natural feed diminishes.

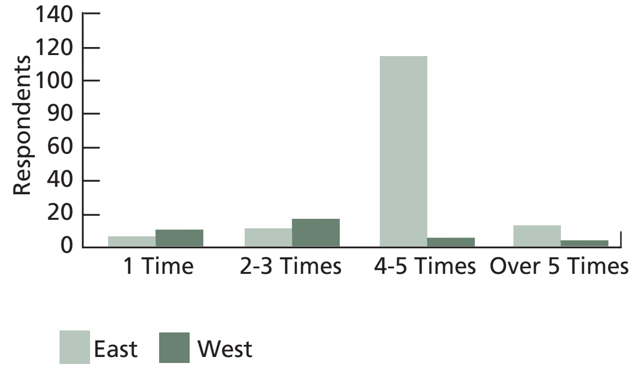



*Figure 4. Frequency of feed application during maximum feeding periods.*

About 93% of the Eastern respondents applied feed both day and night, while 65% of Western participants fed during the day only. About 84% of the Eastern and 75% of the Western respondents who fed both day and night applied between 25 and 75% of the daily ration during the day (Figure 5).

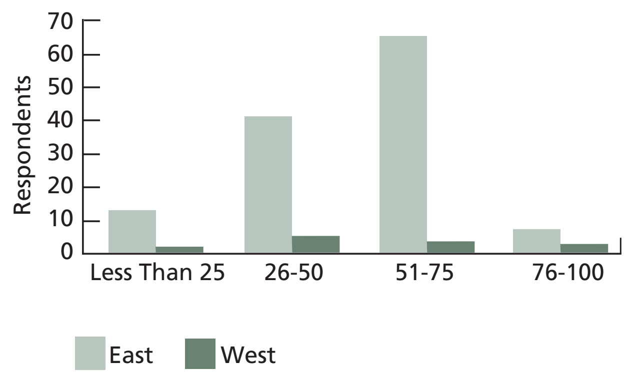



*Figure 5. Percentage of daily feed ration applied during the day if feed applied both day and night.*

## FEEDING TRAYS

Feeding trays are used to monitor feed consumption and estimate adjustments to ration size. Especially in large ponds, however, observation of a limited number of trays is not an adequate measure of actual feed consumption. Considerable day-to-day variations in feed consumption occur due to water quality fluctuations, overcast weather, molting activity, light intensity, natural productivity, and other factors.

Only five respondents did not use feed trays. About 87% of respondents used 10 or fewer trays per hectare, 9% used 11 to 20, and only seven respondents used more than 20 trays per hectare to monitor consumption.

*Nearly all survey participants reported the use of feed trays.*

There were no predominant trends in how often trays were checked. Responding farms from the Eastern Hemisphere most often checked trays 91 to 120 minutes after feeding. Western respondents most often checked trays after 120 minutes.

## FEEDING RATES

About 43% of Eastern Hemisphere and 39% of Western Hemisphere respondents based feed rates and quantities on feed consumption from feeding trays, while about 5% of Eastern and 13% of Western farms used survival estimates, average size, and feeding tables. Fifty percent of the East and 48% of the West respondents used a combination of these criteria.

High feeding rates have important implications for farm profitability, water and effluent quality, and pond management. They typically relate to high stocking densities, high water exchange rates, use of mechanical aeration, and advanced progression of the culture cycle.

About three-quarters of both the Eastern and Western respondents reported daily feeding rates over 25 kilograms per hectare (Figure 6). Only 22% of the survey participants applied over 100 kilograms per hectare, and 9% fed over 200 kilograms per hectare daily.

Many factors are used to adjust feed quantities in feeding trays, which was reflected in the survey responses. In the Eastern Hemisphere, there were no clear trends in the factors used for adjustments, while about 43% of the Western respondents indicated low dissolved-oxygen (D.O.) levels as a factor. Overall, 28% of respondents

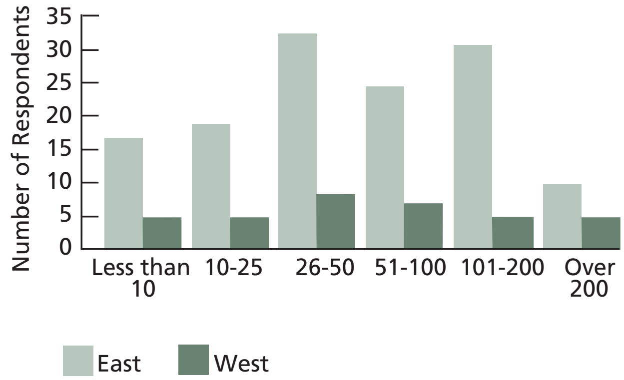



*Figure 6. Maximum daily feeding rate (kg/ha/day).*

reported low D.O., and 22% mentioned extreme water temperature or excessive plankton blooms. About 22% reported other factors.

*Dissolved-oxygen levels are one of the factors used to review and adjust feed application levels.*

## FEED COSTS

For delivered crumble feed, 57% of the Eastern but only 4% of Western respondents indicated costs of less than U.S. $0.25 per kilogram. Eighty percent of the Western and 15% of the Eastern participants reported feed costs of $0.25 to $0.75 per kilogram. About 14% of respondents indicated costs over $1.00 per kilogram.

For delivered pelleted feeds, about 41% of the Eastern and 13% of the Western Hemisphere respondents indicated costs of less than U.S. $0.25 per kilogram. About 77% of the Western but only 15% of Eastern farms reported costs of $0.25 to $0.75 per kilogram. About 14% of respondents indicated pelleted feed costs over $1.00 per kilogram.

### TECHNICAL ASSISTANCE

Eastern survey participants reported other shrimp farmers (26%) and feed manufacturers (22%) as their primary sources of technical assistance, while Western respondents called on consultants (25%), and other farmers and other sources (21% each).

No government staff was used by Western respondents, while 10% of those from the Eastern Hemisphere chose this category. Several respondents indicated other sources of support, including university staff and their own research and development departments.

*Feeding practices must be continually adjusted to answer natural and induced changes in feeding activity and environmental conditions.*

### RESEARCH

Improved feed management will involve the reassessment of goals and expectations. New constraints like reduced water exchange and increased pressure to improve the quality of effluents and use of land and water resources, and feed ingredients of marine origin, are also likely.

Areas of priority for further research include:

- Increased knowledge of biological and chemical processes in production ponds and tanks that affect animal behavior, including feeding activity.
- Maximized use of natural productivity, and nutrient recycling and retention in shrimp flesh.
- Optimized overall management of production systems (ponds, tanks, raceways), of which feed management is only a component in a sequential and additive process from stocking to harvest.

Feeding practices must be continually modified to account for natural and induced changes in feeding activity as animals grow and/or environmental conditions change. Knowledge of shrimp behavior and continuous feedback on pond environmental parameters and shrimp populations are critical for successful feed management.

*Although feed management varies by species, location, and other factors, the goals are always to deliver strong growth and good health while controlling inputs and the impacts of feed wastes.*

## Recommendations

Shrimp feed management is a critical aspect for cost-efficient, environmentally responsible shrimp production. Appropriate practices produce maximum shrimp growth and survival concurrent with the lowest feed conversion, while reducing feed inputs and minimizing the impacts of effluents. Inadequate feed management can lead to suboptimal production and promote the onset of diseases and water quality problems.

Efficient feed management is the summation of sequential steps that include feed selection, reception, storage, handling, and application. When to feed requires determining activity patterns and associated feeding frequency, which are subject to change with geographic location; culture species, age, size, and stocking density; and environmental and other stimuli.

Feed ration calculations involve the estimation of survival, population size and biomass, and size distribution. Evaluating and adjusting feed inputs requires regular population sampling and monitoring of various water quality parameters. Shrimp are bottom feeders, and it is difficult to estimate their feed consumption unless feed trays or lift nets are used.

### FEED SELECTION

Each farm develops its own feed quality requirements based on such criteria as pellet size, uniformity, water stability, and attractability. Moisture, protein, and lipid content are additional factors.

The aquafeed selected must fulfill the known nutritional requirements of the targeted species. It must be fresh and free of mycotoxins and pesticides, and have low pollution potential. The feed should have attractants and natural foods to improve feed palatability and promptly stimulate its consumption. Attractants can improve feed perception and feeding response by as much as 50%. The addition of enzymes and highly digestible ingredients increases nutrient assimilation and reduces excreted materials.

## FACTORS THAT AFFECT FEED CONSUMPTION

Biotic and abiotic factors affect shrimp feeding behavior, including species, age, and size; the availability of natural food; water quality; molting; and feed quality. It is important to understand these factors to make proper and timely management adjustments.

***Species, age, and size.*** Some shrimp species are more aggressive than others in their feeding and foraging behaviors. Feeding rate is initially high and decreases as the animal grows and approaches maturity. Daily growth immediately following pond stocking can be 12 to 15%, but decreases to 1 or 2% toward the end of the production cycle.

***Availability of natural food.*** When natural food is very available, the demand for formulated aquafeeds is reduced. This is typical during the first few weeks following stocking, when the biomass of stocked shrimp is low, until a critical biomass equivalent to the natural carrying capacity of the pond (generally between 200 to 250 kilograms per hectare) is reached. After this, added formulated feed becomes increasingly important to supply the nutritional requirements of the shrimp.

***Water quality***. The most important water quality parameters are temperature, dissolved oxygen, pH, and salinity. Shrimp are poikilothermic animals. The environment determines their temperature, which affects metabolic rates and feeding.

For each parameter, animals have a range of tolerance and a narrower optimum range that promotes growth, survival, and overall well-being. Extreme temperatures and low dissolved-oxygen levels reduce feeding rates. Interestingly, the recommended levels of dissolved oxygen were traditionally accepted at 2.5 to 3.0 parts per million, but there is evidence that for stressed and/or sick animals, this level should be at least 4.0 ppm or higher.

*Improper feed storage can reduce feed quality and attract pests. Feed should ideally be stored inside for protection from sunlight, rain, and potential pests.*

## FEED HANDLING AND STORAGE

Poor storage and handling of feeds can result in product deterioration, reduced feed attractability and palatability, possible nutritional deficiencies and disease outbreaks, reduced growth rates and overall production, and pest infestations.

Feed management at shrimp production facilities starts upon the arrival of a feed shipment. A few randomly selected bags should be examined for physical integrity. Bags should be weighed and inspected for signs they were previously opened and then resealed. Twice a year, feed samples should be collected from new shipments and analyzed for proximate composition, mycotoxins, and selected pesticides, if pertinent.

*Feed samples should be tested for composition and residual chemicals on a regular basis. Photo courtesy of Grobest.*

Most feed manufacturers provide general guidelines for handling and storage. These include:

1. Store feed in a dry, cool, and well-ventilated area protected from sunlight and rain.
2. Rotate stock using older feed first. Feed should ideally be used within the first month after manufacturing, and should not be stored more than three months.

3. Feed bags should be stacked on pallets to prevent direct contact with floors, walls, or the ground and allow adequate ventilation, cleaning, and placement of rodent traps.
4. Clearly mark and maintain different types of feeds separately. Pay particular attention to segregating medicated and nonmedicated feed.
5. Avoid excessive handling of feed bags. Rough handling increases the incidence of fines and thereby increases feed losses.

Nutrient losses occur when essential vitamins degrade as feed ages, particularly under storage conditions of high ambient humidity and temperature. Feed manufacturers commonly incorporate high levels of vitamins to allow for these losses, and also employ stabilized forms of vitamins. Antifungal agents can help control the bacteria and mycotoxin-producing molds that can develop in feeds under the warm and moist conditions prevalent in shrimp-farming areas.

However, additives do not guarantee feed quality. For example, various vitamins in artificial feeds can be lost in minutes if feed bags are left uncovered under direct exposure to the sun's ultraviolet rays. This is common during transport from feed mill to farm and after bagged feed is distributed to ponds.

Many insects and rodents can damage stored aquafeeds and are also vectors for diseases and molds. To prevent the entry of animals, block doors and windows to storage areas with screening materials. At many farms, it is common practice to keep cats and nonpoisonous snakes to control rodents.

*Wind and other weather conditions can reduce the effectiveness of mechanical feed blowers.*

## FEED APPLICATION AND DISTRIBUTION

There are many ways to apply formulated aquafeeds to shrimp production systems. In larger ponds, aquafeeds are often applied via manual broadcast from boats or mechanically by blowers mounted on vehicles or towed along levees. In small, intensive systems, automatic feeders with timing mechanisms can be used. At farms in several countries, all feed is applied using feeding trays.

The advantages of mechanical feeding include the ability to feed more pond area, more often, with fewer employees. But vehicle-based feeding requires farm roads in good condition, and the dimensions of ponds can affect feeding efficiency. Blower feeders typically propel feed pellets about 30 meters in a band about 5 meters wide, so the centers of large square ponds would not receive much feed. Winds and rainy periods that deteriorate roads can also restrict mechanical feeding.

With hand feeding, feed can be distributed evenly in any size pond. Wind and rain do not interfere with hand feeding as much as with mechanical feeding. Efficient supervision is required, however, and labor and fuel costs are higher than for mechanical feeding. As equipment and personnel move from one pond to the next, biosecirutу can also be a problem.

Early in the growout cycle, it is important to distribute feed evenly throughout ponds. Many farms with larger ponds apply feed from boats that follow marked stakes spaced throughout the ponds. As the cycle progresses, managers must be aware that shrimp react to the changing microhabitats in ponds. Animals avoid areas where anaerobic sediments accumulate and noxious compounds such as hydrogen sulfide are present. Particularly at the end of growout, these areas include internal drainage canals and areas close to the drainage structures.

*Since shrimp generally avoid shallow areas of ponds, excess feed can accumulate there.*

Shrimp often move to deeper areas within ponds during the day to avoid light. Therefore, very shallow areas or those with anaerobic sediments should not receive any feed during daylight hours. However, it is also important to consider that shrimp distribution in ponds is not uniform. As explained below, several factors influence how animals distribute themselves in ponds.

## FEEDING FREQUENCY

All formulated aquafeeds have an ideal feeding rate range that optimizes animal growth and feed efficiency. This range varies depending on species, animal age and weight, density, water quality, availability of natural foods, stress, and other factors. At many farms, feeding is based on tables that do not properly consider the natural feeding habits of shrimp or their physiological state.

Increasing the frequency of feeding generally produces immediate benefits, including reduced nutrient and feed loss, and increased growth and feed utilization efficiency. In Asia it is a widespread practice to feed up to seven times daily. Because *L. vannamei* are considered by many to be less nocturnal than *P. monodon*, Western farms typically feed one to three times daily, usually between the morning and late afternoon.

Because of the greater night activity exhibited by *P. monodon*, many farms in Asia provide most of the daily ration during night hours. This practice has also gained acceptance in some Latin American farms in recent years.

Daytime feeding for *L. vannamei* has also been reported as good as night feeding. Increased feeding frequency significantly affects growth in this species, but multiple feedings may not be advantageous for some static culture systems. The cost-effectiveness of multiple feedings must be evaluated for different shrimp species, aquafeeds, and culture systems.

In general, a minimum of two feedings per day should be implemented at the beginning of the production cycle. As the cycle progresses, the daily schedule should be increased to three or four feedings, and up to six feedings during the last several weeks of the production cycle.

*As the growout cycle progresses, many shrimp must be fed several times a day.*

## FEEDING RATES

Feeding based on tables is still widely practiced. Daily rations are calculated based on estimates of density, mean individual animal weight, survival, and body weight percentages. With increasing experience, each farm develops its own in-house tables.

The major drawback to these feed calculations is the difficulty of accurately estimating survival rates, particularly when dealing with small animals in large ponds. Several factors can affect feeding rates, including poor water quality (low dissolved-oxygen levels, temperature extremes, pH fluctuations, toxic gases from decaying bottom conditions), plankton population changes, and molting cycles. Feed consumption changes due to these stressors can usually be detected by monitoring feed trays.

Feeding rates are best adjusted based on population sampling, monitoring of environmental parameters, the use of feed trays, and experience. Rates are usually adjusted weekly based on sampling estimates for average shrimp body weight, population distribution, and shrimp biomass. As animals grow, the feed amounts decrease as a percentage of the total shrimp biomass, but the total amount of feed increases proportionally

Sampling is generally carried out every one or two weeks using nets cast from boats or pond dikes. Personnel new to the sampling procedure must be closely supervised, since they tend to bring back the largest animals instead of collecting a random sample. Estimates of population size and survival rates can be remarkably inaccurate due to shrimp activity (molting, lunar/tidal cycles) and human error. It is important for farms to establish in-house sampling methods to quickly and accurately estimate shrimp populations.

*By serving as shrimp-sampling systems, feed trays can help detect diseases, administer medicated feeds, and estimate shrimp survival.*

## FEED TRAYS

Feed trays are simple, cost-effective tools to apply feed and monitor feed consumption in shrimp production systems. They prevent over- and underfeeding, reduce stress, and promote faster growth. They provide early detection of diseases, controlled administration of medicated feeds, and better estimates of shrimp survival and harvests.

The disadvantages of using trays to feed entire ponds include greater costs, training, and supervision. Two people are required daily for 12-hour shifts for every 10 hectares of pond. But additional construction and equipment costs are reportedly balanced by the reduced feed costs.

When trays are brought to the surface, they usually have some shrimp along for the ride, providing an opportunity for experienced personnel to inspect and assess a sample of animals. Interpreting the amounts of feed left in trays can be subjective, so whenever possible, the same people should perform this task. The same concern should be applied to operations like cast netting.

Although a few feeding trays can be used to monitor feed consumption and estimate adjustments to rations, they may not be suficient to provide an accurate measure of feed consumption, especially in large ponds.

When used as indicators of consumption, about five trays per hectare are used in ponds below six hectares in size, while one to four trays per hectare is appropriate for larger ponds. A small percentage of the ration is placed in the trays distributed throughout the pond. Trays are checked about two hours later.

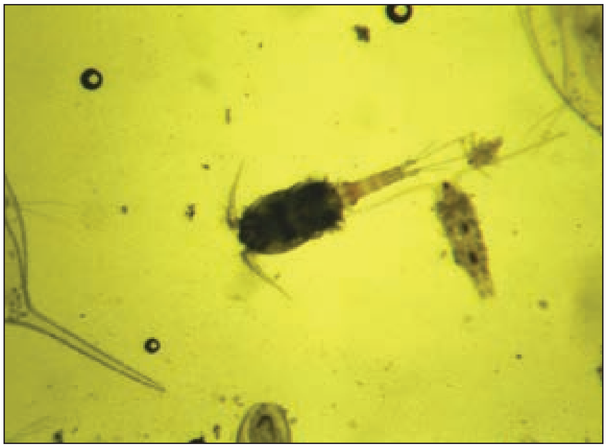
When the entire ration for a pond is applied in trays, it requires many more trays and is much more labor-intensive, but can produce very precise feed consumption estimates and feed conversions.

Various authors have published standard tables that can be used to make adjustments to feeding rates based on the feed left on feeding/monitoring trays. In addition, feeding adjustments can be made based on changing pond water conditions determined after morning and afternoon water quality monitoring. Water temperature, dissolved oxygen, and pH are the most relevant parameters, with tables also available for these parameters.

## NATURAL PRODUCTIVITY

Natural productivity plays a major role in shrimp ponds. Plankton blooms and microbial and benthic community productivity improve and maintain water quality, including adequate levels of dissolved oxygen, pH, ammonia, nitrate, and nitrite.

Yet natural pond production is often underestimated by nutritionists and feed manufacturers who formulate diets that are suited for high stocking densities but probably not justified at the semi-intensive densities prevalent in many areas.



*Natural organisms in pond water can supplement commercial feeds.*

Management of natural productivity involves two main components: pond preparation between production cycles and routine water and soil monitoring and quality maintenance. The objective of pond preparation is to provide the stocked animals a stress-free growout environment with optimal environmental conditions and an ample supply of food organisms.

The objective of pond monitoring and maintenance is to ensure that the pond bottom and water reflect the best possible conditions for optimal shrimp growth and survival. The relevance of natural food production in the diets of penaeid shrimp is well documented – over 50% of the growth carbon in shrimp tissues can originate from grazing on pond biota.

The film of bacteria and other microorganisms generally constitutes 5 to 10% of the mass of detrital particles. Detritus-feeding organisms derive nourishment by stripping the microorganisms from the detrital material as it passes through their guts. Fecal pellets can be recolonized and the process repeated until all the organic material is utilized.

By taking advantage of the recycling capability of organic detritus within the culture environment, nutritionists and pond managers have the opportunity to reduce feed costs, improve feed conversion, and reduce environmental impacts, as well.

The microbes and detritus in pond water can affect the abundance and species composition of shrimp gut flora, stimulate digestive enzyme activity, and enhance the nonspecific immune response in shrimp by stimulating serum agglutination.

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# FARM

# *Disease Testing And Treatment*

GLOBAL AQUACULTURE ALLIANCE

# Disease Testing And Treatment

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## Principles

Diseases, and viral diseases in particular, are a serious concern in shrimp culture. Diseases can survive from one crop to the next as free-living pathogens or harbored in vectors in puddles of water that remain in pond bottoms. Also, pathogens and their vectors can be contained in water added to fill ponds, maintain water levels, or effect water exchange.

Postlarvae stocked in ponds can be infected with disease. Diseases can also spread from one pond to the next via the water supply, birds and other animals, and workers or their equipment. Water discharged from shrimp farms for water exchange or during harvest can spread disease from one farm to another.

Shrimp are cultivated under crowded conditions, and pathogens can spread easily from a single infected shrimp to others. Diseases spread especially rapidly when shrimp are stressed by low dissolved-oxygen concentrations in culture water or other adverse environmental conditions. Once a disease problem occurs in a pond, control by therapeutants is difficult, and some therapeutants can leave residues in shrimp tissue.

Shrimp farms should develop shrimp health management protocols that rely upon disease testing and prevention rather than disease treatment. It is especially important for shrimp farms to reduce their dependence on antibiotics and refrain from using banned antibiotics entirely.

## Survey

### GLOBAL LOSSES TO DISEASE

The purpose of the Disease Testing and Treatment section of the Global Shrimp OP Survey was to determine the global impact of diseases and the status of disease control measures at farms. Since only 19 respondents from the Eastern Hemisphere and 27 respondents from the Western Hemisphere participated, the sample was not representative, and any conclusions are tentative.

Overall mean disease losses were 16% in the Eastern Hemisphere and 28% in the Western Hemisphere, but the coefficient of variation was 100%, so comparison of the difference between the two hemispheres is not possible. The calculated mean overall loss was about 22%. Taken over the global shrimp-farming industry, this would convert to approximately 140,000 metric tons of a total 700,000 metric tons, or an economic loss of about U.S. $1 billion at a shrimp price of $8 per kilogram.

*Since crop losses to diseases like White Spot Syndrome can come quickly, prevention is the best approach to disease control.*

This may be a low estimate, given that yearly losses to White Spot Syndrome Virus (WSSV) alone reportedly reflect this amount. Whatever the case, the loss is enormous and indicates that further investment in research to reduce losses would be worthwhile.

To check the consistency of those responding to the survey, a correlation analysis was made between reported survival and disease losses. It suggested some degree of inconsistency on the part of those responding to the survey. On the other hand, it is possible the responders gave survival data for successful harvests and did not include low survivals from severe disease outbreaks.

According to the survey, big losses were more common in the West than East. This may have resulted from the fact that aquaculture ponds tend to be much larger in the West than the East. Indeed, a correlation analysis of lost production and pond surface area (Figure 1) suggested that larger ponds tended to have higher losses than small ponds.

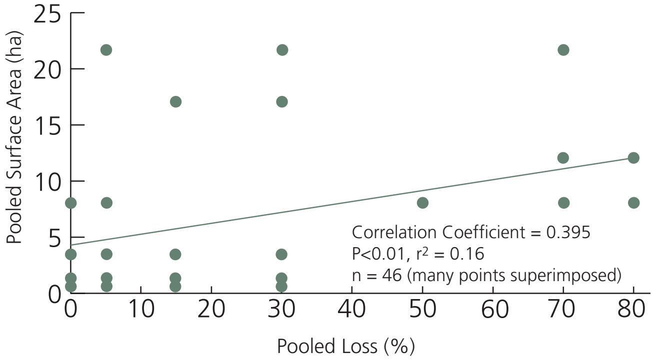


*Figure 1. Correlation between loss to disease and pond surface size for pooled data from the Eastern and Western Hemispheres. A significant positive correlation suggested larger ponds have larger losses.*

A significant positive correlation was also obtained in a comparison of pooled data for pond age and percentage of lost production (Figure 2). Although the relationship was not linear, the correlation coefficient was higher than that for the relationship between loss and pond surface area. It suggested that older ponds tended to have more disease problems than newer ponds. Perhaps there is a build-up of pathogens or the pond environments undergo adverse changes over time. This correlation should be further investigated.

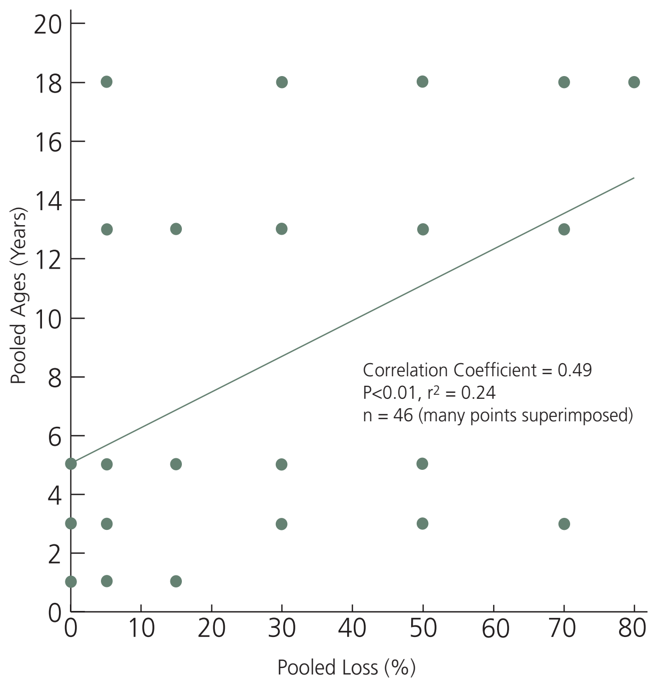


*Figure 2. Correlation between pond age and production loss for pooled data from East and West. A significant positive correlation suggested that older ponds have larger losses.*

Surprisingly, there was a negative correlation between stocking density and loss on farms in data pooled from the East and West (Figure 3). Higher stocking density correlated with lower loss, which seemed to go against logic. One would expect more stress and more subsequent disease loss at higher stocking densities. The negative correlation was probably not causal but resulted from the higher losses at Western farms where low stocking densities were used.

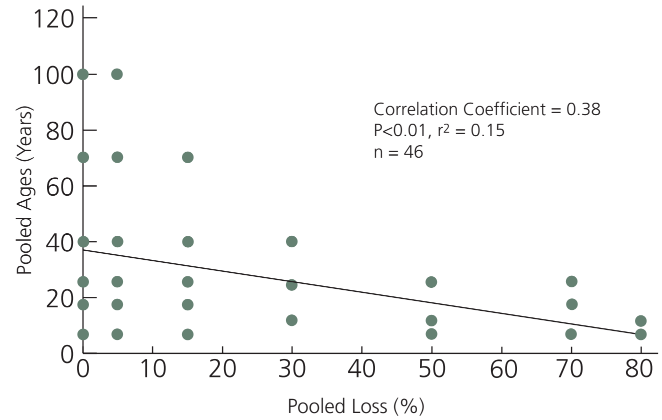


*Figure 3. Correlation between stocking density and production loss for pooled data from East and West. A significant negative correlation suggested that higher stocking densities resulted in lower losses.*

## CAUSES OF DISEASE LOSSES

With respect to disease agents, viruses were the most common causes of losses for both East and West (Figure 4), although they were proportionally more significant in the West (71%) than the East (44%). This was consistent with published literature.

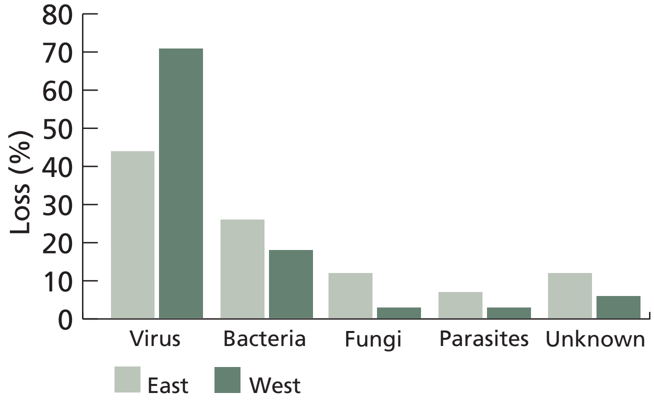


*Figure 4. Proportional losses attributed to different pathogen types. This clearly shows that viral pathogens are the most important cause of losses.*

About 37% of farms from the East and West reported no losses to viral pathogens, while 37% from the East and 10% from the West reported losses below 10%. Losses in the range of 20 to 60% were more common in the West (30%) than the East (10%), while only and a small percentage of farms reported losses of 81 to 100%.

The tendency for higher losses in the West may have resulted from the arrival of WSSV, to which Eastern farmers have had more time to adapt. Overall, the estimated loss would be about $600 million of the total $1 billion estimate given above for 2001. Because the only effective way to control viral pathogens is prevention, biosecurity improvement must remain a top priority for shrimp farmers.

About 42% of farms from the East and West reported no losses to bacterial pathogens, while 31% from the East and 39% from the West reported losses of less than 10%. Losses in the range of 11 to 20% were higher in the East (21%) than the West (10%). No farm reported losses to bacteria more than 40%.

In spite of the overall lower loss to bacteria when compared to viruses, the loss is obviously very substantial for the global industry. A conservative guess would be in the range of U.S. $200 million of the total $1 billion given above. Together, viruses and bacteria accounted for about 80% of the overall losses in 2001.

*Although production losses to bacteria are lower than those caused by viruses, they are considerable.*

## ON-FARM DIAGNOSIS

With few exceptions, trends for determining health status in the East and West were similar. Sixty to 90% of farms used gross examinations, and 80 to 95% used microscopic examinations and considered them highly reliable. However, the use of stains in rapid examinations was surprisingly low (50 to 60%). Histological examination of tissue sections showed much more use (64%) in the West than the East (28%).

The reasons for this difference are unclear, although high costs and location were the two constraints most often cited as the cause of unfulfilled needs. To overcome the high costs of tissue embedding, sectioning equipment, and trained specialists, shrimp farms can consider contracting with local hospitals or universities to do this work. Unfortunately, this may not be possible in remote locations.

On the other hand, simple methods for fixing and staining whole mounts and smears would be available to any farm lab with a microscope. These comprised 83% of the East and 96% of the West respondents. An effort should be made to increase the proportion of farms that use these techniques.

*Basic microscopic examination was available to most farms in the survey.*

Use of microbial culture and identification was approximately 50% for respondents from both the Eastern and Western Hemispheres. With respect to molecular methods, DNA dot blot assays were much more common in the West (52%) than the East (22%). Polymerase chain reaction (PCR) testing was more common in the East (41%) than dot blots, but still lagged behind PCR use in the West (72%).

Use of in situ hybridization and immo-blot assays was low in both the East and West, although proportionally higher in the West. For both these tests, the response of no opinion was around 50%, perhaps indicating lack of familiarity with the methods.

Since monoclonal antibody detection techniques have recently been published for a number of shrimp viruses, it should be relatively easy to adapt them for use in simple pondside assays. On the other hand, these tests and PCR tests have the disadvantage that they usually target only one or two pathogens.

They cannot replace histological examination for overall health assessment, especially for routine monitoring of shrimp. They are most useful for outbreak confirmation, and screening broodstock and postlarvae in specific disease prevention programs.

## DISEASE CONTROL

It was encouraging to find from the survey that antibiotic use was relatively uncommon. For both East and West, 40% of the respondents did not use antibiotics, and

50% seldom used them. When used, antibiotic efficacy was reported good by about 40% of the survey participants and variable by about 60%.

Given these relatively poor efficacy rates, it appears there is room for further reduction in antibiotic use by wider dissemination of information on management practices that reduce problems with bacteria. In addition, there is a need for more research on alternatives to antibiotic treatments.

Probiotics or pond conditioning microbes have been proposed as one alternative antibiotics in shrimp ponds. Strictly speaking, probiotics should be living microbes that become residents in the gastrointestinal tracts of target organisms. So far, this has been demonstrated for only one probiotic for shrimp. Most other products advertised are recommended for use as "water conditioners."

A recent publication on several such conditioners showed little effect on pond bottom soil and water quality, but did show a significant ($P < 0.1$) improvement in survival for unexplained reasons. Curiously, it did not seem to matter which product was used, and all contained different microbes or microbe mixes. The basis for the results needs to be explained in a proper scientific manner.

A phenomenon known as "quorum sensing" may possibly be involved. In this process, the activity of pathogenic bacteria can be altered in such a way that they are no longer capable of producing toxic substances. The number of microbes needed to exert this type of effect need not be high. Very little work has been done on this phenomenon in shrimp ponds and hatcheries, and further investigation is required.

*In some parts of the world, probiotics and varied other pond treatments are available in local shops.*

In the survey, the use of probiotic products contrasted sharply between East (87%) and West (36%) respondents. Few considered probiotics ineffective, although the effectiveness was given as variable or good by only 40 to 60% of users.

The use of vaccines for either bacteria or viruses was very low. It is well known that shrimp do not produce antibodies and respond to bacteria and fungi with nonspecific, pattern recognition molecules. On the other hand, little is known about shrimp responses to viral pathogens. Shrimp may respond to them in a specific, adaptive way.

If so, there may be room for the development of vaccinelike reagents called tolerines that would allow shrimp to better survive infection by viral pathogens. The relevant research remains to be done.

Thus, for the time being, the major focus for shrimp farmers should be biosecurity measures aimed at keeping pathogens out of the culture system. This may not be feasible with bacteria, but its effectiveness has been amply demonstrated with viral diseases. The ultimate goal of the industry should be to use domesticated broodstock certified free of specified viral pathogens, and rear them in biosecure ponds.

The survey question concerning negative factors for disease control brought a poor response from the West and a better one from the East. Needs were expressed for equipment, experts, information, and reagents (Figure 5). Overall needs were generally higher in the East. Disease laboratory equipment ranked as the top need for both regions.

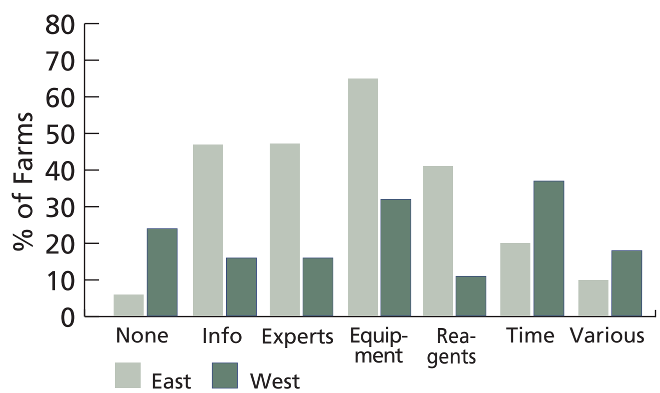


*Figure 5. Farms reporting negative factors hindering the improvement of disease control.*

About 35% of respondents overall indicated they had no barriers to meeting their needs. Of those indicating barriers, high cost (45%) and location (35%) were the most common barriers for both East and West farms.

Obviously, there is a need to improve the distribution of information. It is also possible the needs for equipment and experts can be reduced by accelerating the development and widespread adoption of simple antibody detection methods for use by relatively untrained personnel. To achieve this goal, investment is needed in research and extension training.

With respect to priorities in disease control, answers to nine items in the questionnaire were analyzed by assigning a value of 9 to the highest priority and 1 to the lowest to achieve total scores for each item. The top five priorities are shown in Figure 6.

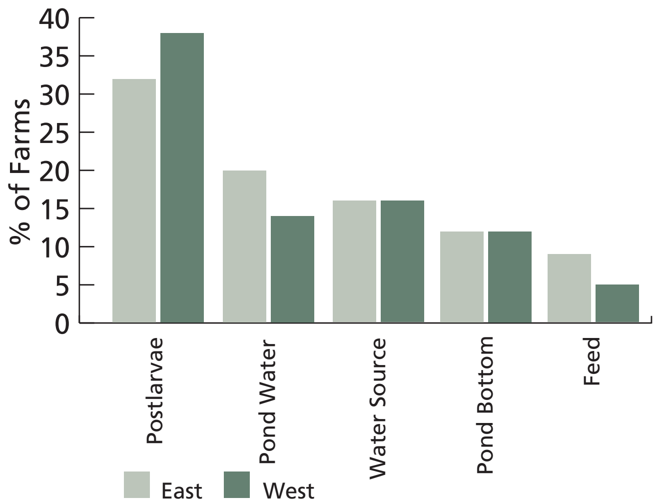


*Figure 6. Five top priorities in disease control.*

Opinions were almost identical for the East and West, with most farms giving highest priority to postlarvae with a mean score of 33. This was followed by pond water (17), water source (16), pond bottom (12), feed (8), personnel (7), treatments (5), equipment (2), and other (1).

## Recommendations

According to the survey, the minimum figure for global loss to disease in shrimp aquaculture in 2001 was approximately U.S. $1 billion, with about 60% attributable to viruses, 20% to bacteria, 12% to other agents, and 8% to unknown causes. It is obvious the highest priority should be given to solving the problems related to viruses and bacteria.

The most effective means of doing this is to develop domesticated shrimp stocks that can be certified free of major pathogens and rear them in biosecure culture systems. This objective is easier to achieve with *P. vannamei* because domesticated and genetically selected stocks are already available for these shrimp.

It will take longer with *P. monodon*, since domestication and breeding programs for this species lag considerably behind. In the interim, farmers of *P. monodon* will have to depend upon screening of captured broodstock and their postlarvae using sophisticated PCR and perhaps monoclonal antibody-based techniques.

Biosecurity in culture systems could be improved by satisfying the outstanding needs of the industry in terms of equipment, experts, information, and reagents. In addition, more research in the realms of molecular, microbial ecology, and biochemical engineering could help develop models for the stabilization of pond environments in closed recirculating or limited-exchange systems.

*Shrimp farmers should begin growout with postlarvae free of disease and monitor their health throughout production.*

This survey showed that producers are well aware of the economic consequences of disease, and many were attempting to develop systematic practices for preventing disease. GAA and other organizations should continue to promote practices that lessen the opportunity for disease to enter farms or spread among them.

It was encouraging that most respondents to the survey did not use antibiotics for treating shrimp diseases. However, because of the serious consequences to exporters of residues of certain antibiotics in shrimp, GAA and other organizations should continue to encourage responsible shrimp health management procedures.

Although the format of this report does not support a detailed list of recommendations, the following points are offered to shrimp producers.

- Disease-free postlarvae should be obtained for stocking ponds.
- Producers should improve their ability to conduct on-farm disease diagnosis.
- Diseases should be prevented through sound biosecurity programs and the prevention of animal stress through maintenance of high-quality water and bottom soils in ponds.
- Antibiotics use should be curtailed.

There still is much to learn about methods of disease transmission, identification of diseases, and procedures for managing ponds to lessen the impacts of diseases. Thus, a major recommendation is that more funds from governments, international agencies, and the shrimp industry be invested in research on shrimp health management.

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# FARM

# *Effluent Water Quality*

GLOBAL AQUACULTURE ALLIANCE

# Effluent Water Quality

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## Principles

Shrimp ponds discharge effluents in response to intentional water exchange, heavy rains, and draining for harvest. Effluents from water exchange and rainfall are similar in quality to normal pond water. These effluents are not highly concentrated with potential pollutants, but often have higher concentrations of nutrients, suspended solids, and organic matter than the natural water bodies into which they are released.

The final 20 to 25% of water released when ponds are drained for harvest has more potential pollutants, especially suspended solids, than effluents discharged at other times. Shrimp farm effluents can cause eutrophication and sedimentation in the water bodies they enter.

Most shrimp farms cannot be operated without discharge. Water exchange may be necessary at many locations to prevent evaporative losses from causing excessive salinity. Water exchange also is an important water quality management tool at semi-intensive farms for preventing dissolved oxygen depletion when dense phytoplankton blooms occur. Heavy rains can exceed the storage capacity of ponds and overflows cannot be avoided. Shrimp ponds also must be drained to facilitate harvest.

Nevertheless, shrimp farms should be operated in a manner to minimize effluent volume and avoid adverse effects of the effluents on receiving water bodies. The same water body often serves as both water supply and effluent recipient for shrimp farms. Thus, responsible effluent management protects not only the environment but also the water supply for shrimp farms.

Probably the most important facet of effluent management is to prevent excessive nutrient inputs by adding fertilizers only when necessary to promote plankton growth and using high-quality feeds according to feeding practices that minimize waste. The reduction of water exchange can also provide great benefits in effluent management. This action provides longer hydraulic retention of water in ponds and enhances the capacity of ponds to assimilate wastes through natural processes. It also will lessen effluent volume.

Diseases can spread from one farm to another via the water supply, so reducing water exchange can be a deterrent to disease transmission. Finally, sedimentation basins and wetlands can lessen the loads of pollutants in farm effluents. The monitoring of effluent quality is necessary to confirm the effectiveness of the measures taken.

In some nations, governments issue effluent discharge permits that specify concentration limits for selected water quality variables. To achieve certification in programs like Aquaculture Certification Council, Inc.'s Best Aquaculture Practices and other certification programs, shrimp farms must also comply with defined water quality criteria.

## Survey

In the Effluent Water Quality section of the Global Shrimp OP Survey, there were 60 responses from Thailand, 12 from other countries in the Eastern Hemisphere, and 24 from the Western Hemisphere (Figure 1).

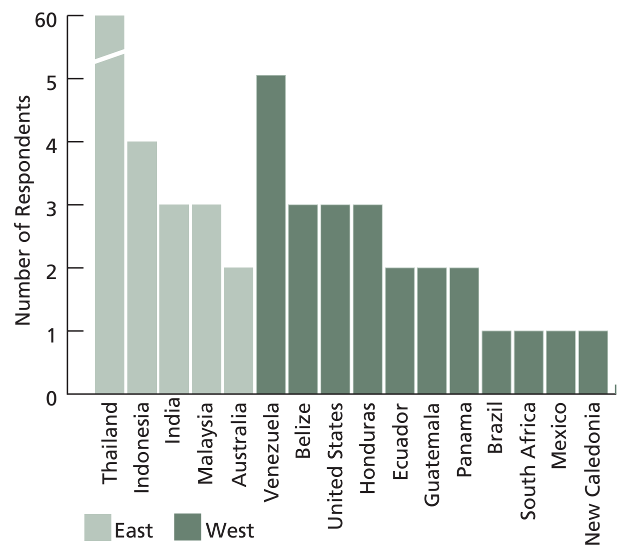


*Figure 1. Distribution of survey responses.*

### EFFLUENT PERMITS

About half the respondents in both hemispheres were required by government to have effluent permits. Eight of the Thai farms required to have permits were not obligated to monitor effluent water quality. In the West, all but one of the permits required effluent water quality to be monitored. Lending agencies for 34% of the farms from the East and 42% of those from the West required monitoring. Some respondents had initiated effluent monitoring programs even though they were not required to do so by governmental or lending agencies. Farms in this category included four from Thailand and five from countries in the West.

*Monitoring of dissolved oxygen is a requirement of some regional use permits.*

*Table 1. Best Aquaculture Practices effluent water quality criteria.*

| Variable (units) | Initial Value | Final Value (after 5 years) | Initial Value |
|---|---|---|---|
| pH (standard units) | 6.0-9.5 | 6.0-9.0 | Monthly |
| Total suspended solids (mg/L) | 100 or less | 50 or less | Quarterly |
| Soluble phosphorus (mg/L) | 0.5 or less | 0.3 or less | Monthly |
| Total ammonia nitrogen (mg/L) | 5 or less | 3 or less | Monthly |
| 5-day biochemical oxygen demand (mg/L) | 50 or less | 30 or less | Quarterly |
| Dissolved oxygen (mg/L) | 4 or more | 5 or more | Monthly |
| Salinity | No discharge above 800 mg/L chloride into freshwater | No discharge above 550 mg/L chloride into freshwater | |

In the East, most permits specified monitoring of pH, dissolved oxygen (D.O.), and ammonia. Some permits also required farms to monitor biological oxygen demand (BOD) and total nitrogen (T.N.). In the West, monitoring requirements for pH, total suspended solids (TSS), BOD, and T.N. were included in most permits. Only two farms, both in the East, were asked to monitor chlorophyll a (Figure 2).

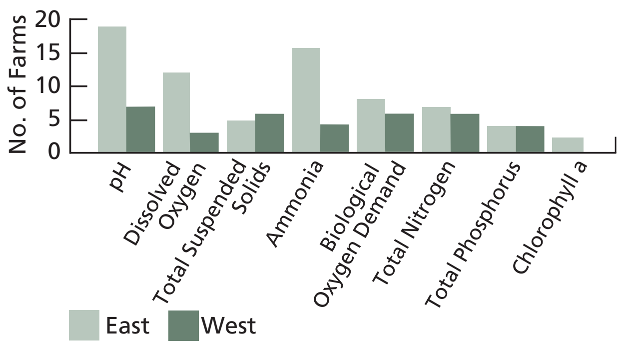


*Figure 2. Water quality parameters required in effluent permits.*

## WATER QUALITY VARIABLES

Water quality variables and concentration limits differed considerably among permits. Most permits specified a minimum pH of 6 to 7 and maximum pH not to exceed 8.5 to 9.5. The main exception was in the East, where four farms had a minimum pH limit of 7.5.

Maximum limits for TSS concentrations varied widely. Most were set between 40 and 60 milligrams per liter, although limits of 200 and 350 milligrams per liter also were reported.

In the East, a minimum D.O. limit of three milligrams per liter was most common, but permits for some farms specified limits of four and five milligrams per liter. Only two farms in the West had permits with D.O. concentration limits. The limits were three milligrams per liter for one farm and five milligrams per liter for the other. The effluent limitations defined by GAA's Best Aquaculture Practices standards (Table 1) are generally stricter than those reported in the survey.

Reporting of effluent quality data normally is done at monthly intervals or more frequently, but a small number of permits allowed less frequent reporting (Figure 3). Seventeen of 18 farms in the East that were required to report weekly were in Thailand.

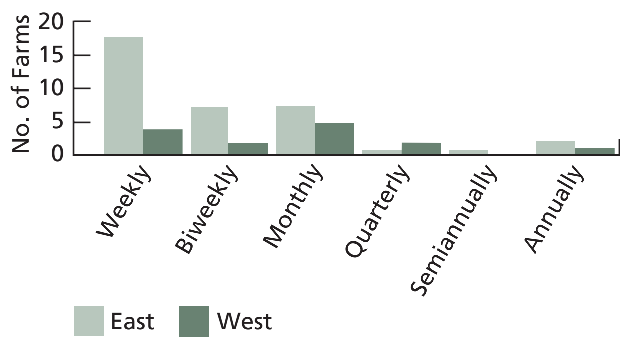


*Figure 3. Reporting intervals required by effluent permits.*

Effluent samples usually are collected by farm staff and analyzed at the shrimp farm or sent to a private or government laboratory (Figure 4). However, at 24 farms in Thailand and one farm in Indonesia, governmental regulatory agencies assumed the responsibility for both collecting and analyzing effluent samples.

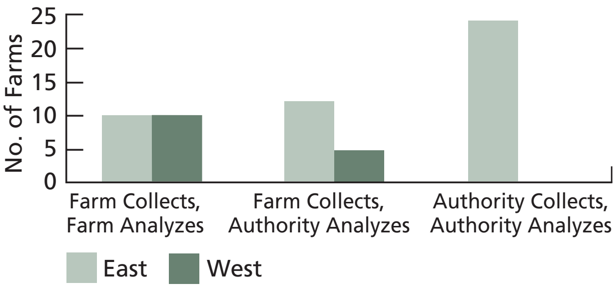


*Figure 4. Responsibility for collecting and analyzing effluent samples.*

Eleven respondents reported they were required to calculate and report loads of selected variables in effluents. As only one respondent provided a limit expressed in load units, there was likely a general misunderstanding of this question. Nevertheless, approximately half the respondents were required to measure and report the total volume of effluents, and they would be able to calculate loads.

## WATER EXCHANGE

In the East, the majority of farms reported average daily water exchange below 2% of pond volume, and only one farm exchanged more than 10%. Although the group with less than 2% exchange was dominated by responses from Thailand, it also included farms in Malaysia, Australia, Indonesia, and India (Figure 5). Water exchange rates are generally higher and more varied in the West.

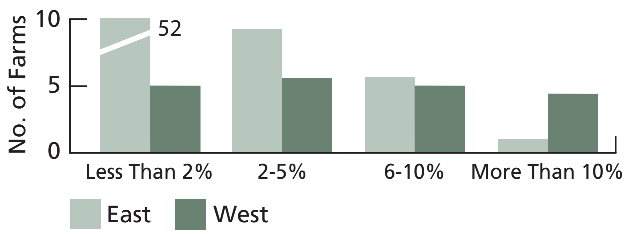


*Figure 5. Average daily water exchange.*

More than half the respondents said they were attempting to lower water exchange below present rates, and most had a target rate of 3% per day or less.

## WATER TREATMENT, REUSE

Settling basins are installed at 32% of the farms from the East and 40% of farms from the West. All but one was installed voluntarily. Most (71%) farms had settling basins with area less than 25% of the total pond production area, while the remainder reported between 25 and 50% of production area. In one response from Thailand, settling basins accounted for more than 75% of the total production area.

*Although they represent only a small area of large farms, sedimentation basins can provide effecitve water treatment.*

Most settling basins had a hydraulic retention time of less than 24 hours, although some respondents from Belize, Malaysia, and Thailand reported retention times greater than 48 hours. In about half the cases, the settling basins were used to treat effluent before discharge into natural water bodies, while the remainder also used them to treat water before reuse.

Eight farms reused less than 25% of their exchange water, one farm reused 25 to 50% of exchange water, and five farms from Belize and Thailand reused more than 50% of their exchange water. The remaining farms did not reuse exchange. Single farms in Indonesia, Malaysia, Belize, and United States, and 13 farms in Thailand reported that water drained from ponds at harvest was reused.

About 25% of respondents indicated they cultured fish, bivalves, or seaweed in discharge canals or settling basins to improve water quality. While most reported this did not generate significant income, three farms gained more than 11% of their total income from polyculture activities (Figure 6). The shrimp farms with the highest incomes from fish culture, in Thailand and Indonesia, reported that more than 20% of their net profits was from fish.

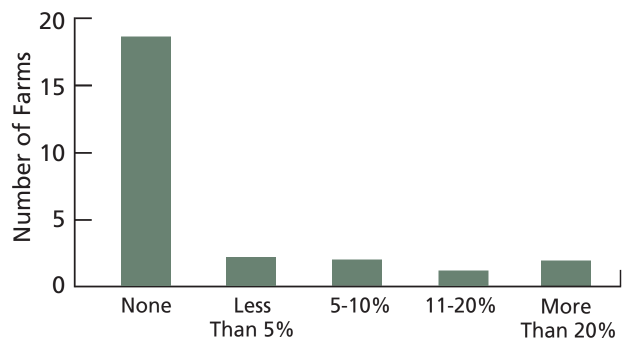


*Figure 6. Proportion of farm profit from polyculture.*

### EFFLUENT OUTFALL, QUALITY

Most farms apparently attempted to discharge effluents downstream of the farm water intake to prevent mixing effluent with intake. The outfalls usually were into estuaries or the sea, but sometimes released into ecological sensitive areas. Thirty-seven percent of those responding said that final effluent outfalls were into mangrove areas or other sensitive habitats.

Typical concentrations of water quality variables in effluents were provided by 75 participants from 15 countries. The usual concentration ranges were: pH, 7-9; dissolved oxygen, three to seven milligrams per liter; total nitrogen, less than four milligrams per liter; total phosphorus, less than 0.3 milligram per liter; total suspended solids, 20 to 60 milligrams per liter; biochemical oxygen demand, less than 30 milligrams per liter. These findings are encouraging, because the reported values generally are in compliance with GAA's Best Aquaculture Practices effluent standards.

*Oxidation ditch for recirculating pond water.*

## Recommendations

Farms in many countries are not required to have effluent permits or monitor effluent quality. However, most farms that monitor effluents reported concentrations of water quality variables within acceptable limits. There also are encouraging signs that the environmental performance of shrimp farming is improving. Most farms attempt to reduce water exchange, many farms have installed settling basins, and some farms are reusing exchanged water.

Several procedures are available for developing management strategies that reduce the volume and improve the quality of shrimp farm effluents. These include reducing nutrient inputs and applying erosion control to lessen the suspension of soil particles. With these procedures in place, treatment of effluent before final discharge into natural water bodies may not be necessary.

However, at most shrimp farms, it would be possible to pass effluents through sedimentation basins or wetlands if application of good practices does not improve effluent quality. Some nations require discharge permits with numerical limitations for selected variables, and Best Aquaculture Practices certification of shrimp farms requires compliance with a water quality standard containing numerical water quality criteria.

### BEST MANAGEMENT PRACTICES

The Global Aquaculture Alliance recommends a series of best management practices (BMPs) in its Coded of Practice for Responsible Shrimp Farming. The code for effluents and solid wastes includes several BMP recommendations. Canals and embankments should be maintained to reduce erosion. Water exchange should be minimized as is feasible. Efficient fertilization and feeding practices should be implemented to promote natural primary productivity while minimizing nutrient inputs.

Ponds should be drained in a manner that minimizes resuspension of sediment and prevents excessive water velocities and associated erosion in canals and at effluent outfalls. Where feasible, pond effluents should be discharged through a settling basin or mangrove forest. Outfalls should be designed so no significant impacts on natural waters occur beyond the mixing zone. Shrimp pond effluents should not be discharged into freshwater areas or onto agricultural land.

*The stabilization of embankments with stone can reduce erosion and suspended solids in pond water.*

### CAREFUL FEEDING

Several BMPs from the code of practice for feed management directly affect the quality of farm effluents by promoting efficient feeding and avoiding wasted feed and excess nutrients. For example, pellet binders and suitable manufacturing techniques should be used to provide water-stable pellets. Feed management practices should assure that shrimp consume the maximum amount of supplemental feed and do not leave feed decomposing on pond bottoms to cause degrade water quality. Feeding rates should be adjusted for shrimp biomass, appetite, and pond conditions. Feed trays can be used to monitor feeding and prevent under- or overfeeding.

Efficient supplemental feeding depends upon applying feed uniformly over ponds several times during a 24-hour period. Feeding of uncooked organisms such as fish and invertebrates should be discouraged, because they can carry disease and foul pond waters.

Stocking densities must be within a range that optimizes production, favors good water quality within ponds, and minimize wastes. Harvesting methods should minimize nutrient loads, suspended solids, and organic matter in draining effluent.

Erosion control during farm operation should be implemented through appropriate aerator location, proper embankment slopes and vegetation cover; protection of embankments below the water line where necessary; and monitoring of sediments in each pond at the end of each crop. Farms also should use appropriately designed settlement ponds and water recirculation.

*Embankment stabilized with grass.*

## SEDIMENTATION BASINS

Settling basins offer an excellent method for treating effluents released during shrimp harvests, especially the final, highly concentrated effluent. These basins remove coarse solids suspended in water during the final phase of pond draining. Studies have shown that 60 to 80% of TSS and 15 to 30% of BOD can be removed in a settling basin with only six to eight hours of water retention.

In addition to removing coarse solids, settling basins can remove solids from effluents released during water exchange and in the initial phase of pond draining. This is important because a literature review of shrimp farm effluents done recently for GAA revealed that total suspended solids were consistently above 100 milligrams per liter in effluents at many farms. Most water quality permits allow only 50 milligrams per liter TSS.

Settling basins should be 1 to 2 meters deep. Water is introduced at the surface on one side and discharged from the surface on the other side. The size of the basin depends upon the inflow rate and retention time necessary for removing coarse solids.

Basins gradually fill in as they accumulate sediment and must be cleared out occasionally to maintain adequate performance. Settling basins should be constructed larger than necessary. Dual settling basins should be constructed so one can be used while the other is cleaned.

While some farmers think settling basins require too much space, this is not necessarily true. Consider a 500-hectare shrimp farm with 1-meter-deep ponds operated with an average daily water exchange of 2%. The daily water exchange volume would be 100,000 cubic meters, and on a day when 20 ha of ponds are completely drained, the effluent volume would increase to only 300,000 cubic meters per day. To provide a retention of eight hours, a 100,000-cubic-meter settling basin representing about 1.5 to 2% of the farm area would be necessary.

On small farms, the proportion of farm area devoted to settling would have to be much larger, often 10 to 20% of farm area.

## BIOFILTRATION SYSTEMS

A recent report by the World Bank, Network of Aquaculture Centers in Asia-Pacific, World Wildlife Fund, and Food and Agriculture Organization Consortium on Shrimp Farming and the Environment described an integrated mangrove wetland-shrimp farm operating in Colombia since 1996. At this site, shrimp farm effluent is recirculated through a 120-hectare mangrove area.

Mangroves and shrimp ponds have mutually supportive functions. Mangrove wetlands treat effluents by removing suspended solids and nutrients. This activity in turn enhances mangrove productivity.

In discussing the costs and benefits of the integrated mangrove-farm system, the author reported that construction cost in 1995 was about U.S. $100,000. When the large area of the biofilter is considered, the system is inexpensive in comparison to the cost of constructed wetlands reported by other authors.

It is difficult to estimate the value of the benefits. The most significant benefit of the system is probably the removal of BOD and TSS from pond effluent. Because BOD and TSS values are lower in farm effluent than in supply water from the lagoon, the environmental authority does not charge any contamination tax to the farm.

*Mangroves offer the potential for limited effluent biofiltration.*

Another potential financial benefit of the recirculation system is the prevention of blue-green algae blooms in the estuary, which in the past caused off-flavor to develop in shrimp.

This effort is a positive example of an attempt to develop responsible aquaculture in coastal areas, but also reveals the need for further research. Mangroves are sensitive and important coastal ecosystems, and discharge of shrimp farm effluents into some mangroves could result in excessive sedimentation or other degradation.

*Constructed wetlands can also help treat effluents. Photo courtesy of Rosati.*

Researchers have also examined the use of constructed wetlands planted with aquatic macrophytes to treat farm effluents before they are discharged into natural water or returned to ponds for reuse. The initial results appear promising, but the technology has not been widely proven.

Researchers in Australia are considering an integrated approach to reduce nitrogen waste from shrimp farming. Their work has shown that developing an understanding of the dominant processes in shrimp ponds and treatment systems can provide a means of targeting research. The integration of research on shrimp genetics, nutrition, and pond management will likely have the most significant impact on reducing nitrogen wastes.

*The true impacts of effluents depend on more than nutrient concentrations.*

## EFFLUENT STANDARDS

A number of nations have formulated effluent limits for concentrations of selected water quality variables in shrimp farm effluents. High concentrations of potential pollutants in effluents do not necessarily indicate effluents are harming the environment. Moreover, limits on such potential pollutants do not assure that natural waters will be protected from pollution.

Nutrient concentration is only one aspect of effluent quality. Environmental impacts also are affected by volume of discharge, dilution, the assimilation capacity of the receiving environment, and other sources of pollutants.

Because of temporal variability in farm effluents, the monitoring frequency imposed by regulatory agencies – typically monthly – leads to the application of effluent standards.

Best Aquaculture Practices certification requires producers to monitor water use and calculate a water use index (cubic meters of water per kilogram of shrimp) and pollutant load index (kilograms pollutant per metric ton of shrimp). Certified farms must show improvement in effluent management over time by documenting that the volume of effluent and pollutant load are declining.

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# FARM

# *New Production Technologies*

GLOBAL AQUACULTURE ALLIANCE

# New Production Technologies

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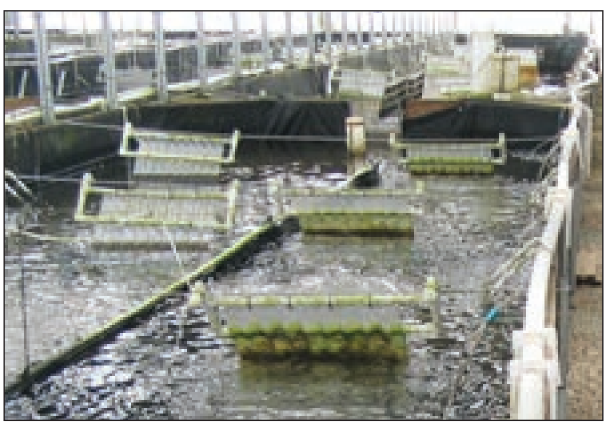
## Principles

Shrimp farming has not been the beneficiary of nearly as much university- and government-sponsored research and extension as fish farming. Thus, producers have had to invest heavily in consultant services and on-farm trials in developing efficient culture methods. Moreover, in addition to the usual production challenges, shrimp farming has been beset with several new challenges during the past five years.

There have been increased incidences of viral diseases, non-governmental organizations have accused shrimp farming of widespread environmental and social irresponsibility, and the prices that farmers receive for shrimp has declined. The shrimp-farming industry must respond proactively to these challenges in order to remain profitable.



*Super-intensive indoor systems implement aeration, recirculation, and temperature control.*

Some governments in shrimp-farming nations have become involved in assisting shrimp farmers with disease, environmental, and marketing problems. For example, governmental agencies in Thailand and Colombia have been particularly active in attempting to assist producers. Of course, the producers must work with these organizations, improve their understanding of the sources of the problems, and adopt new technology.

Some examples of new technology available to producers are low-water-exchange systems, closed systems, closed systems based on heterotrophic food webs, adoption of environmentally responsible production practices, effluent treatment, farm-reared broodstock, disease-free postlarvae, lower-protein content feed, and biosecurity. In addition, more effective marketing strategies inform consumers of the increasing use of responsible production practices and potentially improve prices.

## Survey

The Global Aquaculture Alliance and other organizations have diligently promoted better practices and new technologies for years. Thus, the objectives of this survey were to determine the extent to which shrimp producers try and adopt new technologies, and ascertain if producers feel the new technologies are successful. The number of producers who responded to the survey represent a small fraction of all shrimp producers, but the results are indicative of producers' responses to new challenges facing the industry.

### DISEASE CONTROL

The most often cited reason for trying a new technology in both the Eastern (East) and Western (West) Hemispheres was control of emerging diseases (37% and 38%, respectively). Viruses have become ubiquitous in the environments of some shrimp-growing areas. Culture techniques that eliminate or delay the entry of virus particles or carriers into the culture ponds are major areas of experimentation and adoption.

Reduction or elimination of water exchange and increased efficiency of screening incoming water are the major methods being adopted for eliminating the viruses from ponds. Eighty percent of the respondents for both the East and West reported reducing water exchange, (Figures 1 and 2) with over 75% of respondents in both hemispheres reporting a positive outcome for the change.

Reduction in water exchange reduces the chances for introduction of both viral particles and carriers, and also allows farms to introduce finer filtration and, if required, disinfect the water. High rates of water exchange, in the early years of shrimp farming, were thought essential to maintain healthy phytoplankton blooms and remove undesirable nutrients and wastes from ponds.

*Belize aquaculture was a pioneer in sustainable intensive closed-system shrimp culture.*

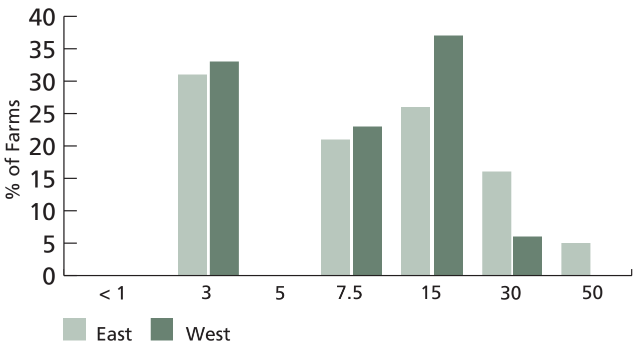



*Figure 1. Frequency of water exchange for both hemispheres during 1998.*

*Filter bags remove vectors or pathogens from incoming water.*

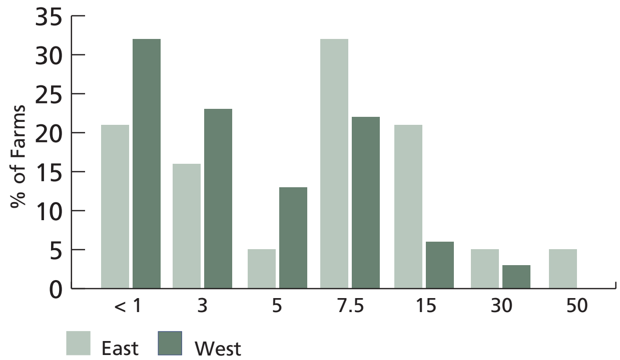



*Figure 2. Frequency of water exchange during 2001.*

However, recent evidence indicates that reduced or even zero water exchange allows the shrimp-farming environment to be both stable and desirable for the growing of shrimp. Instead of removing nutrients through water exchange, ponds develop a microbial community with nitrifying bacteria that oxidize ammonium to nitrate and an extensive heterotrophic microbial community that recycles, converts, and digests wastes and nutrients.

There has been a greater adoption of finer filtration techniques and replacement of gate filters with bag filters in the West than the East. Moreover, 54% and 88% of respondents reported positive outcomes from finer filtration in the East and the West, respectively. Over 50% of the respondents from both hemispheres have adopted filtration mesh sizes of 150-500 microns. Several years ago, only 24% of Western shrimp farms filtered below 500 microns as compared to 42% of Eastern shrimp farms (Figures 3 and 4). Eastern shrimp farmers adopted the finer mesh earlier to deal with carriers of the Yellow Head and White Spot Syndrome Viruses that struck Asian farms before 1995.

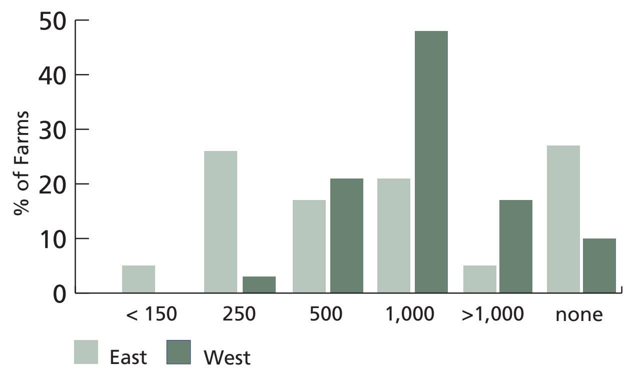



*Figure 3. Screen size of filters used during 1998.*

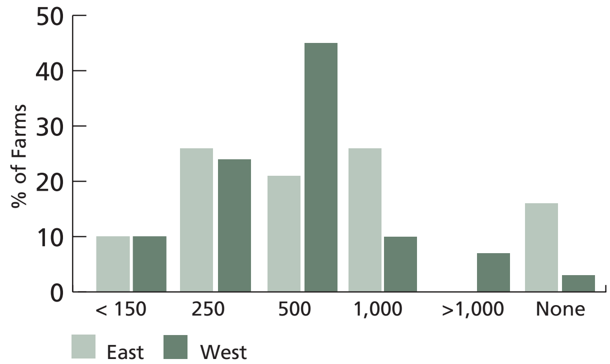



*Figure 4. Screen size of filters used during 2001.*

Disinfection of pond water has been used by Eastern farms much more than Western farms as a method for the elimination of viral particles and carriers. Only 35% of Western farms have tried disinfection of pond water, which is contrasted with 80% of Eastern farms that responded. Eighty percent of the Eastern farms indicated a positive outcome from using a disinfectant on pond water, while only 50% of the Western farms reported a positive outcome.

It is more feasible to disinfect the smaller, intensive ponds in the East than the larger, semi-intensive ponds in the West. Chlorine was the most common disinfectant in both the East (70%) and West (80%). Most farms used a dose of 20-50 mg/l.

Other technologies concerned with increasing survivorship in ponds deal with improving pond environments, especially those which result from reduced water exchange. Development of heterotrophic communities; reduction of protein levels in feeds; manipulation of pond dynamics by the addition of iron, silicate, molasses, or other complex carbohydrates; and application of probiotics to pond water and soil have been adopted by many farms. As water exchange is reduced, the chances for introducing infectious agents fall, and the development of heterotrophic communities creates a healthy environment for shrimp.

*This intensive inland shrimp farm uses lined ponds, heavy aeration, water treatment, and recirculation.*
*Photo courtesy of Oceanboy Farms, Florida, USA.*

Heterotrophic communities recycle nutrients to increase the natural productivity of ponds, and reduce the amount of wastes in the ponds through digestion, assimilation, and conversion. Carbon often becomes limiting in ponds, especially when feeds that contain over 20% protein are applied. For this reason, many farms reducing water exchange tend to create heterotrophic communites that could benefit by reducing the protein level in feed.

*Water changes from clear to green (phytoplankton) to dark (bacterial floc) in high-density lined ponds.*

Less protein in the diet results in more carbon relative to nitrogen, leading to a healthier environment with fewer water quality problems. Farms also have added chemicals such as iron supplements to absorb sulfide wastes, or molasses/complex carbohydrates to improve the carbon:nitrogen ratio in the water to allow the microbe community to work more efficiently.

The survey indicated that the East has been faster to experiment with and adopt strategies that encourage heterotrophic community development. Seventy percent of Eastern respondents reported trying to promote heterotrophic communities, and, 72% of them reported a positive outcome. In the West, only 45% of respondents reported trying to promote heterotrophic community development, but over 90% of the farms that tried reported a positive outcome. Again, pond size and culture intensity probably explain the differences in the development of this technology.

To date, the survey indicated only 40% of the farms in both hemispheres have tried to lower the amount of protein in feeds, but those farms that tried lower protein content reported a high rate of satisfaction (75% East and 100% West) (Figures 5 and 6). The higher degree of success in the West probably had to do with the culture species.

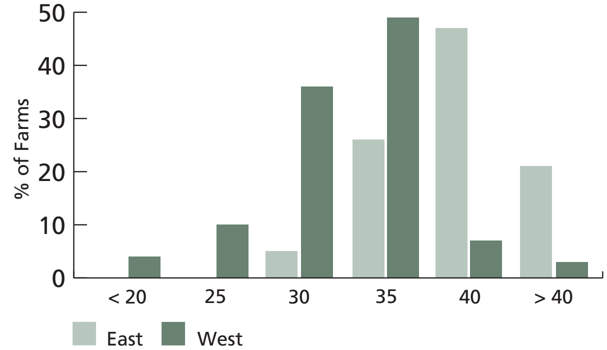



*Figure 5. Protein level (%) in diets used during 1998.*

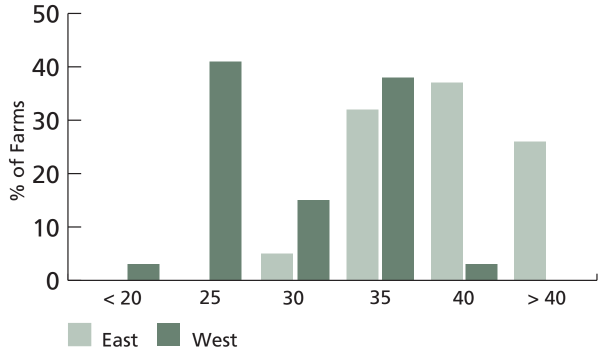
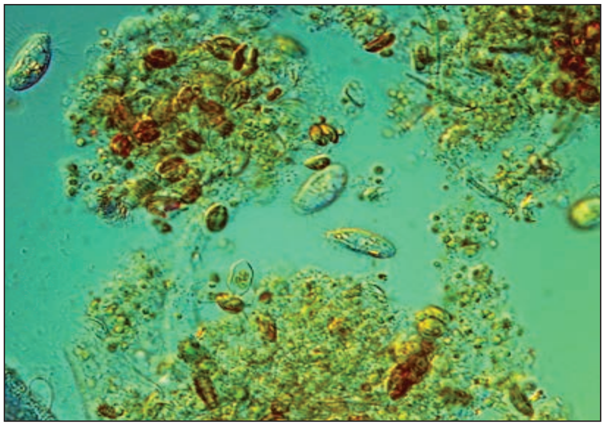



*Figure 6. Protein level (%) in diets used during 2001.*

This species, *L. vannamei*, utilizes detritus more efficiently for food than *P. monodon*, which is commonly cultured in the East. Detritivores probably respond better to lower-protein feeds and detrital food chains than more carnivorous ones. Currently, 58% of Western shrimp farms reported using diets with a protein level less than 30%, whereas 95% of Eastern shrimp farms used diets with protein levels greater than 30%.

Eastern farms also reported more experimentation with pond additions such as probiotics and molasses than their Western counterparts. Ninety-five percent of the Eastern respondents reported trying probiotics in pond water and/or soils, with 88% of these reporting a positive outcome. Along with the probiotics, 75% of Eastern farmers reported using molasses/carbohydrates and other pond additives to enhance the microbial community. A minority (30%) of Western farms reported trying probiotic products in pond water or soils, and only 45% reported trying to add chemicals or molasses to modify the pond environment.



*Microscopic view of bacterial floc. Such flocs represent natural food sources that supplement commercial feeds. Photo courtesy of Shawn Moss.*

Again, differences in the size of ponds and intensity of culture methodology define what technologies farms are likely to try. Economically, probiotic use often is restricted to ponds for intensive shrimp culture. Probiotics have gained wide acceptance in Asia, where they often are applied to ponds to introduce bacteria that are specialized at conversion of pond waste products or reduce the occurrence of *Vibrio* bacteria.

## INCREASED PRODUCTION EFFICIENCY

Many of the technologies that were tried and in some cases adopted by farms for dealing with disease outbreaks also resulted in higher production efficiency. With the reduced price of shrimp on the world market, increased production efficiency and lower production costs are equally important in enabling shrimp farmers to profit. Reducing feed protein results in a cleaner pond environment and generally results in a lower feeding cost. Methodologies that lower feed conversion, such as the development of heterotrophic systems, can result in lower feed costs and opportunities for increasing production efficiency.

*Round-pond, center-drain technology for shrimp culture.*

Pond liners and the introduction of artificial substrates are two other ideas that can affect production efficiency. Properly installed pond liners result in reduced pond maintenance. They also allow farmers to clean wastes from the pond more effectively and quickly, thereby allowing more production cycles per year because less time is spent in drying and preparing pond soils.

When smooth lining material such as HDPE is used, pond bottoms offer less drag, reducing the amount of mechanical energy from aeration required to keep solids in suspension. Finally, when ponds are lined, there is separation of the pond environment from the soils. There is no chance for viral carriers that can inhabit pond soils to infect the shrimp being cultured in the pond, or for poor soil characteristics to effect pond production.

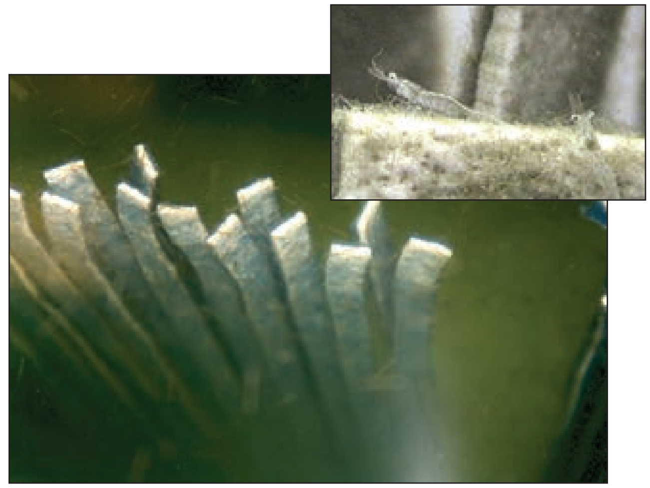
A minority of respondents from both hemispheres have tried liners in production ponds, but those who did generally had a positive result (50% in East, 80% in West). HDPE was the most common material used (58%) with concrete the second most-used material (28%). One farm had used PVC liners.

The capital cost of lining a pond is probably the factor responsible for more farms not trying this technology. The cost of HDPE liners is generally in the area of U.S. $1.20 to 1.50 per meter, and installation can cost 20 to 30% of material costs. Lining of ponds makes sense only for those farms that are using intensive culture technology.

Another idea that can increase pond production efficiency is the use of substrates. Some artificial substrates are suspended vertically in a pond. Others are neutrally buoyant, and after a base is anchored to the bottom, the substrates float into a vertical position.

There are three major rationales for adding substrate. The first is that the substrate provides additional area for the attachment of microbial communities, thereby increasing natural foods in the ponds for shrimp consumption. A second rationale is that it increases the surface area that can be colonized by microbes involved in nutrient transformations, e.g., nitrifying bacteria. The third rationale is that the substrate provides additional habitat for the shrimp and may be important with increasing stocking densities. Because of the considerable cost involved in the installation of artificial substrate, the technology makes most sense for those farms that grow shrimp intensively.

Farms in the East have experimented with artificial substrates more than those in the West. Again, this difference is probably related to the intensity of the culture methods being employed. However, more farms in the East reported either a negative (44%) or a neutral response (22%) to the use of artificial substrates. In the West, only 30% of the respondents reported trying artificial substrates, but of those farms that tried them, 75% reported a positive response. An equal number of farms used commercially available artificial substrates such as Aquamats® or substrates of their own making. The most often reported positive result was an increase in survival, but some farms also reported that the use of artificial substrate resulted in an increase in yield and decrease in feed conversion.



*Artificial substrates provide additional area for microbial communities and habitat for shrimp.*

Polyculture has been tried by combining shrimp culture with either bivalves or finfish. The most notable recent uses of polyculture with finfish have been to offset some of the losses incurred by disease. In Ecuador, Honduras, and Mexico, the polyculture of shrimp with tilapia was tried as a means of reducing the economic impact of Taura Syndrome Virus.

By culturing a fish such as tilapia that is not infected by the shrimp virus, the cost of pond operations can be offset by the fish crop, and the harvest of shrimp can provide the profit margin. In some shrimp farms, clams have been tried with shrimp as a way of utilizing nutrients that settle to the pond bottom, while mussels have been introduced to remove nutrients that are bound in phytoplankton.

Few respondents had tried polyculture of alternative species with their shrimp. Fifty percent of the respondents from the East report trying polyculture, but only 11% of the respondents from the West reported trying alternative species. Of those respondents that tried, 60% from the East and 100% of those from the West reported positive experiences. Species reported as being tested or grown in polyculture with shrimp were tilapia, bivalves, milkfish, mullets, seabass, oysters, and groupers. Tilapia, milkfish, and mussels were the only species tried by more than one farm.

Farmers reported growing alternative fish species in ponds, inlet reservoirs, settling basins, drainage ponds, and special lagoons built in the ponds. Yields of the alternative species ranged from 100 to as much as 15,000 kilograms per hectare per year, with a mean 450 kilograms.

*The polyculture of tilapia and other species with shrimp can offset disease losses and enhance profits.*

## ENVIRONMENTAL IMPACT

Shrimp farming has in the past been characterized by environmental groups as destructive to the environment. As a result, pressure has been felt by shrimp-farming organizations to improve the environmental record of the shrimp-farming industry. Many farms have reduced the amount of water exchange to the environment and some have also installed settling basins to remove nutrients responsible for eutrophication.

Although only 15% of the respondents indicated that environmental concerns were the motivation for change, 50% of all farms in the East reported the use of settling basins. In the West, only 40% of the respondents reported testing the concept. All respondents from the West and 62% from the East reported a positive result in the use of settling to reduce the amount of nutrients released to the environment. The balance of the respondents from the Eastern Hemisphere characterized their experience as neutral.

# Summary

Tables I and II attempt to rank the importance of emerging new technologies by using an index calculated by multiplying the percentage of farms that reported trying the new technology by the percentage of farms that reported a positive outcome from the new technology. Using this index, differences emerged between the West and the East in how they have approached the challenges to profitable shrimp farming. The East has placed more emphasis on development of probiotics and the use of disinfection technologies for dealing with ongoing disease issues, while the West has placed more emphasis on increasing water filtration efficiency. Both have reduced water exchange rates.

The price of shrimp has declined, problems with disease have not abated, and environmental concerns are still raised. These issues have been the forces behind change in the shrimp-farming business. Nevertheless, a minority of participants in the GAA survey participated in the part on New Production Technologies.

*Table 1. Ranking for tried or implemented new technologies in the Western Hemisphere (Relative score = % positive results x % trying/100).*

| Technology | Relative Score | Positive % | Equivalent % | Trying % |
|---|---|---|---|---|
| Finer Filtration | 71 | 87 | 13 | 82 |
| Polyculture | 65 | 32 | 5 | 11 |
| Reduced Water Exchange | 58 | 73 | 13 | 80 |
| Probiotics/Immunostimulants in Feed | 45 | 79 | 14 | 58 |
| Development of Heterotrophy | 40 | 92 | 8 | 44 |
| Reduced Protein in Feed | 40 | 100 | 0 | 40 |
| Environmental Mitigation | 40 | 100 | 0 | 40 |
| Manipulation of Pond Dynamics | 34 | 75 | 25 | 45 |
| Artificial Substrates | 22 | 75 | 12 | 30 |
| Probiotics/Microbes in Water | 19 | 62 | 12 | 30 |
| Pond Water Disinfection | 19 | 55 | 33 | 35 |
| Pond Liners | 14 | 80 | 20 | 30 |

*Table 2. Ranking by relative importance for tried or implemented new technologies in the Eastern Hemisphere.*

| Technology | Relative Score | Positive % | Equivalent % | Trying % |
|---|---|---|---|---|
| Probiotics/Microbes in Water | 84 | 88 | 1 | 95 |
| Pond Water Disinfection | 61 | 79 | 14 | 78 |
| Reduced Water Exchange | 58 | 73 | 13 | 79 |
| Probiotics/Immunostimulant in Feed | 56 | 75 | 25 | 75 |
| Development of Heterotrophy | 50 | 72 | 14 | 70 |
| Manipulation of Pond Dynamics | 50 | 66 | 25 | 75 |
| Finer Filtration | 40 | 54 | 46 | 73 |
| Reduced Feed Protein | 33 | 75 | 12 | 44 |
| Environmental Mitigation | 31 | 63 | 37 | 50 |
| Polyculture | 29 | 61 | 25 | 47 |
| Artificial Substrates | 19 | 33 | 22 | 56 |
| Pond Liners | 18 | 50 | 0 | 35 |

Forty-five percent of participants from the West (29 respondents) completed the survey for new technologies, but only 6% of the participants from the East (19 respondents) did so. Reasons stated for not adopting more new technologies were a lack of capital and lack of proof for the cost effectiveness of the new technologies. Clearly, where farms are small, the merits of expending capital must be well proven before farmers are willing to make investments.

Meetings, publications, and contact with other farmers were all stated as means by which farmers learned of new technologies and made determinations as to which technologies were worthwhile. As shrimp farming becomes more and more competitive, we can expect to see farmers depending more and more on information to make decisions as to which technologies to implement in order to keep profitable. Currently, practices such as reducing water exchange rates, increasing the filtration of incoming water, reduction of protein levels in feed for *L. vannamei*, and use of probiotics in intensive ponds seem to be gaining acceptance as more and more farms experiment with emerging technologies.

*Harvesting with a shrimp pump. Such new approaches require specialized equipment, training, and investment.*

## Recommendations

New technologies available for shrimp farming can be separated into two basic categories. One category includes practices that can be implemented rather easily without appreciable modification of farm infrastructure or major changes in normal operations. This category includes such practices as reducing water exchange, filtration of incoming water, use of feed with lower protein content, and application of probiotics in intensive ponds. It also includes practices that can be used to prevent or minimize possible negative environment impacts. The GAA manual "Codes of Practice for Responsible Shrimp Farming" should be consulted for a list of recommended practices.

The second category includes those technologies that require major modifications of farm infrastructure, which often are most applicable when farms are designed and constructed specifically to accommodate them. The best example is the use of lined ponds, heavy aeration, and low-protein feed to produce *L. vannamei* under heterotrophic culture conditions in closed systems.

Shrimp farmers should strive to adopt the simpler technologies as rapidly as possible. These technologies can reduce the incidence of disease, improve feed use efficiency, minimize environmental impacts, and make shrimp farming more environmentally responsible and sustainable. The new programs for certification of shrimp that are produced under environmentally friendly culture conditions initiated by GAA and other organizations could improve the image of shrimp culture and enhance markets for producers willing to participate.

The more difficult technologies that require major modifications of farms and production practices or that must be installed when farms are built will hopefully be adopted by the industry in the future. At present, relatively few producers are likely to adopt these technologies.

It is encouraging that many producers are willing to be proactive and adopt new technologies. However, there is still much opportunity for improvement in the technology used by shrimp farmers.

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# FARM

# *Mangrove Conservation*

GLOBAL AQUACULTURE ALLIANCE

# Mangrove Conservation

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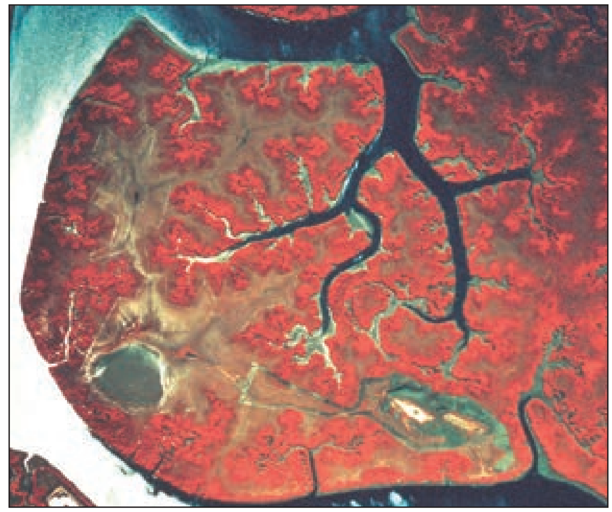
## Principles

One of the major issues in developing coastal management plans in tropical and subtropical regions of the world has been the conflict between developing and expanding shrimp farming and the conservation and management of mangrove resources. The conflict arises because of the use of mangrove forest areas to establish shrimp farms, a practice that resulted in some loss of mangrove forests in different parts of the world over the last 20 years. In addition to the loss of mangroves, some argue that ecological services are also lost.

Mangrove wetlands are important nursery areas. They provide shelter and protect coastal areas from storms and erosion, they are sinks for inorganic nutrients and sediments, and they are exporters of organic matter that is important in coastal food webs. These ecological functions are critical because they are related to maintaining water quality in estuarine waters and enhancing the productivity of economically important fisheries. Mangroves also are important to the livelihoods of poor people who live in tropical and subtropical coastal areas.

Because of an increasing awareness of the negative impacts that shrimp mariculture practices can have on coastal habitats, the shrimp industry has begun to develop better management practices. It now recognizes that mangrove areas are poor sites for shrimp farms and over past years has promoted the siting of shrimp farms outside mangrove-dominated coastal zones.

Analysis of production trends of shrimp ponds constructed in mangrove areas has generally shown that these areas are the least desirable to establish shrimp operations as a result of their high concentrations of sulphur and organic matter, which negatively affect shrimp growth and increase maintenance costs. Thus, successful management plans for shrimp farming in coastal regions depend on the ability of managers to integrate the diverse functions of natural resources such as mangroves and estuaries with shrimp culture to assure sustained economic development.



*This satellite image identifies mangrove forests (red area) in Honduras.*

The wild larvae, effluent treatment, water quality, and erosion control provided by mangrove ecosystems must be evaluated relative to the economic benefits of aquaculture. It is a common conviction that to develop sustainable ecosystem management, it is important to develop culture practices that integrate with mangrove wetland construction, restoration, and rehabilitation, and sustain the environmental quality of estuarine and coastal ecosystems. Thus, it is important to assess how the shrimp industry is integrating mangrove stewardship into its management practices to achieve productivity and sustainability.

## Survey

The Mangrove Conservation section of the Global Shrimp OP Survey consisted of 16 questions that covered issues related to the conversion of mangrove areas to shrimp farm, mangrove rehabilitation and conservation, and mangrove ecological services. Seventeen countries provided responses to the mangrove conservation survey. The total number of farms per hemisphere is shown in Figure 1. Twenty farms in the Western Hemisphere (West) provided information, while only nine farms in the Eastern Hemisphere (East) responded.

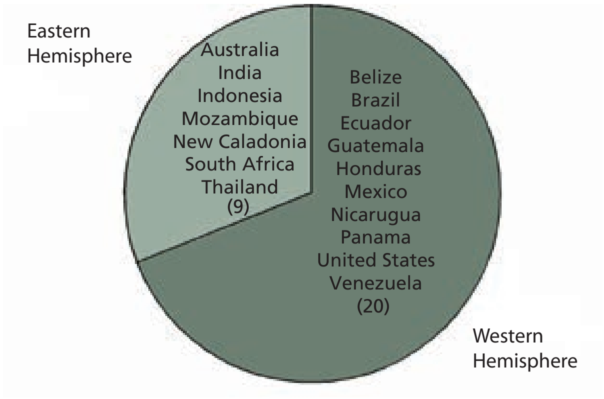



*Figure 1. Countries and number of farms per region participating in the survey.*

Despite the relatively large number of countries participating in the survey from the West, there were few responses from farms within each country. This small sample size, together with the fact that the samples were not collected on a random basis, limits the application of statistical analysis to obtain quantitative trends per country.

Countries with more than one farm responding to the survey included Belize (3), Ecuador (3), Honduras (3), Venezuela (3), Guatemala (2), Australia (2), and Thailand (2). More information is needed from farms in the East before a full comparison between hemispheres can be made. Where appropriate, this preliminary information has been supplemented from other recent work on mangroves and shrimp farming, particularly experiences in the East.

## MANGROVE CONVERSION TO SHRIMP FARMS

Seventy percent of the farms in each hemisphere answered that shrimp farms were not built in mangrove areas. In those cases where mangroves were converted into farms in the West, 40% responded that conversion was performed by the previous landowner and represented less than 10% of the mangrove area (Figure 2).

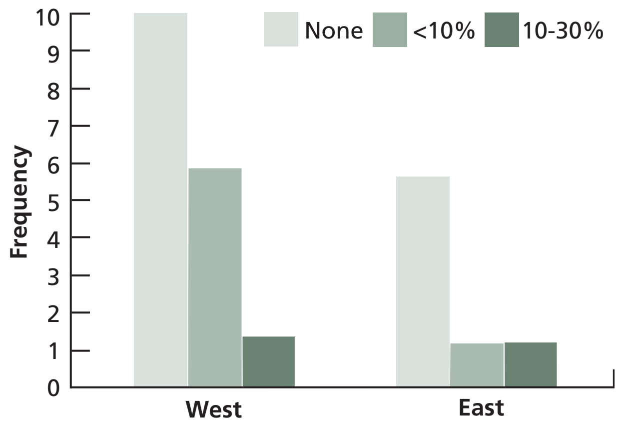



*Figure 2. Portion of farm that was formerly mangrove area.*

Two farms in the East indicated that their facilities occupied 10-75% of former mangrove area.

Farmers also were asked what other regional influences or human activities impact mangroves in their areas. Urban and industrial development, salt production, tanning, effluent water from the shrimp farms, cane farming, and river sedimentation were all reported. Interestingly, wood collection by local communities for cooking and construction was reported as the most frequent human activity to impact mangrove areas in both the West (40%) and East (20%).

Patterns of coastal land use for shrimp aquaculture differ considerably between and even within countries. Reports by the World Bank (WB), Network of Aquaculture Centers in Asia Pacific (NACA), World Wildlife Fund (WWF), and Food and Agriculture Organization of the United Nations (FAO) Consortium on Shrimp Farming and the Environment indicate that countries with little mangrove forest, such as China, Japan, and South Korea, construct ponds on agricultural land of low productivity, or underutilized saline land.

*In the Gulf of Fonseca, Honduras, mangrove stature is reduced due to high soil salinity (white area in foreground).*

In these countries, shrimp farming has had little impact on mangroves, but greater impact on tidal marshes. In countries with significant mangrove resources, farms may be constructed on various types of land, depending on such factors as government policy, availability of nonmangrove land, population pressures, and infrastructure development.

The WB, NACA, WWF, and FAO Consortium concluded that shrimp farming has contributed to the loss of mangroves, particularly within the last 20 years, noting that the greatest losses arose from extensive culture systems that occupied large areas of intertidal land. However, because of the variability and general unreliability of available data, particularly on the status and quality of mangrove forests involved, it is currently difficult to assign a reliable global figure for mangrove losses from shrimp culture.

Estimates suggest that less than 10% of the global mangrove resource has been converted to shrimp ponds. The rate of loss has slowed during past years because of a combination of greater awareness of the value of mangroves and an ongoing trend to build smaller ponds on better sites behind the intertidal zone.

*Natural mangrove regeneration is being evaluated along the Shark River in Florida, USA.*

## MANGROVE REHABILITATION, CONSERVATION

As reported before, mangrove planting is practiced on a limited scale as a mitigation and rehabilitation measure in the West (Figure 3). Eighty percent of the respondents from the West indicated they replanted mangroves for mitigation and rehabilitation purposes, whereas 50% did so in the East.

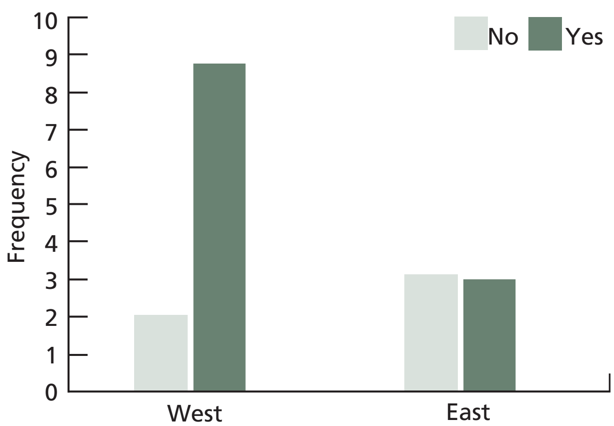



*Figure 3. If mangroves were destroyed in farm construction, were mangroves replanted for mitigation/rehabilitation?*

Red mangrove (*Rhizophora* sp.) was the most common mangrove species used in planting programs in the West, followed by black mangrove (*Avicennia* sp.). Only one farm planted *Laguncularia racemosa* (white mangrove). Less than 40% of the farms in both regions planted mangrove propagules or seedlings around shrimp ponds to control erosion.

Also, 80% of the respondents called their planting programs successful, as measured by the survival of 50% of the seedlings or propagules planted, although there was little information on time scale. In those cases where planting failed, the main cause identified was the lack of technical support, training and a specific planting strategy.

The frequent use of red mangroves for rehabilitation and mitigation programs reflected the lack of technical support in most cases, because the species is planted inland from tidal creeks and around shrimp ponds where environmental conditions are not optimal for their growth. Large planting efforts in the West using red mangroves have failed, costing considerable money and time. This result was not reflected in the survey results because of the small sample size.

In general, there appears to be a need for technical assistance to support successful mangrove planting programs in the West. A recent study of a mangrove plantation functioning successfully as a biofilter on a shrimp farm in Colombia provides much information on the issues concerning such use of mangroves.

The survey provided scarce information for the East, so it was not possible to establish any trends for this region from the survey. The lack of survey information on planting programs in the East contrasted with the number of studies on the ecology and reproduction of mangrove species performed in the region.

*Mangrove seedlings are produced at a shrimp farm for transfer to the sedimentation area (below) to facilitate water purification and reuse.*

Mangrove plantation farms are extensive in several countries of the East, where advanced planting techniques and methods could be applied readily to restore or rehabilitate impacted mangrove areas. For example, in Vietnam, there has been extensive planting of mangroves in the Mekong Delta, and shrimp-farming systems have developed to integrate aquaculture with mangroves. Experiences on mangrove restoration are growing in Asia, and further communication of these experiences in the West should be promoted.

It should be noted that restoration programs in the East primarily involve mangrove planting, but recent experiences suggest that allowing natural mangrove colonization after restoring hydrology can also be highly effective and considerably cheaper in some locations than replanting. Restoration programs already in place in the East can be used as guidelines to develop additional sound mangrove restoration efforts.

*Mangrove poles are cut by local residents for firewood and construction material.*

The percentage of annual operational cost invested in mangrove conservation was low. Three farms assigned 1 to 3% of their annual operational costs, and only one farm dedicated 4 to 5%. Most of the farms in the West (nine) and East (five) did not allocate money to mangrove conservation programs or were not able to provide information (eight farms). Further information on the economics of mangrove restoration based on geographical location and methodologies used is provided in the WB, NACA, WWF, and FAO Consortium report.

Many of the farms indicated that government regulations of shrimp farming were in place (50% and 70% in East and West, respectively). However, the survey did not provide information on the enforcement or effectiveness of these regulations. Only one farm indicated that regulations limit sustainability, and five farms expressed that current regulations need modification.

Apparently, current regulations have allowed significant development of the shrimp industry in both hemispheres, although interaction with governments to establish plans for mangrove conservation is limited. For example, six farms in the West and two in the East reported active collaboration with government, public, and educational institutions, whereas eight farms in the West and three in the East indicated that they occasionally interacted with those institutions (Figure 4). This limited interaction, however, offers opportunities to include conservation and management of mangrove forests within the operational context of shrimp farming.

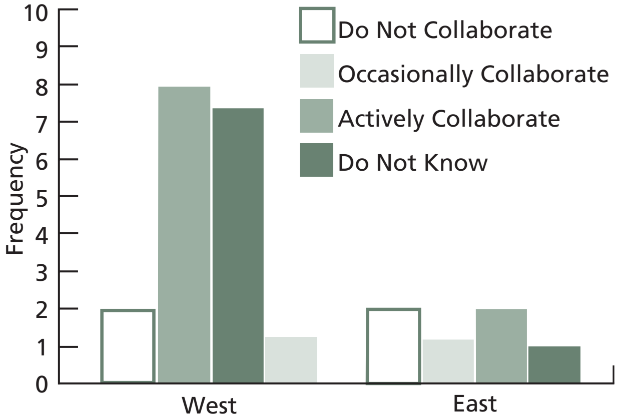



*Figure 4. Degree of cooperation with government, public, or educational institutions to develop plans for mangrove conservation.*

It is clear that extensive efforts and incentives are needed to develop mangrove conservation programs that fit government interests in conserving coastal natural resources and at the same time allow the sustainable expansion of the shrimp industry.

Some experiences in Ecuador show the improved enforcement of regulations through a unique collaboration between the shrimp industry and a local nongovernmental organization (NGO). Such partnerships between industry and NGOs are encouraged as a means of properly identifying and finding joint solutions to conflicts.

## MANGROVE ECOLOGICAL SERVICES

As reported in the preliminary analysis of the survey, there was a general perception by the respondents in both regions that mangroves offer ecological services that benefit shrimp farm operations. These services include treatment of effluent (17 responses), buffer zone to prevent trespassing (14), protection from storm surges (11), aesthetic value (11), and habitat for wild larvae (9).

Other services provided by mangrove forests reported by farmers were improvements in fisheries production, maintenance of nutrient conditions in water sources, and the protection of farm infrastructure from winds. One farm indicated that conservation of mangroves within shrimp operations promoted good relationships with local fishermen. Another farm said the conservation of mangroves was important because they represent an "ecosystem."

These responses are encouraging, as they indicated there are common interests among shrimp growers and environmental groups for conserving mangrove resources. Given the history of social and political conflicts between mangrove conservationists and shrimp producers, particularly regarding the expansion of the industry in coastal regions, it is understandable that few efforts directed to implement management strategies have linked both mangrove ecology and sustainable shrimp aquaculture.

The treatment of effluents by mangrove forests was identified by shrimp growers as one of the main ecological services in the survey. Thus, further research programs should be aimed at evaluating the efficiency of tertiary treatment of shrimp pond effluents by mangrove wetlands, building on existing experiences such as those in Colombia. This type of program can help select better management practices through specific linkages between shrimp operations and the functional properties of mangrove ecosystems.

## Recommendations

Additional research on integrating shrimp farms and mangrove ecosystems would allow the shrimp industry to develop state-of-the-art, cost-effective environmental technologies that reduce the environmental impacts of the industry and at the same time help conserve mangrove resources.

There are already attempts to evaluate mangrove treatment of shrimp pond effluents as an ecological service for shrimp farming, but further efforts are needed to perform pilot studies in different environmental settings to determine operational costs and efficiencies under different management practices. Experience also suggests that special government incentives, as in Colombia's "pollution tax" on nutrient discharge from ponds, can be effective in promoting the integration of mangroves into shrimp-farming areas.

*Mangrove trees growing at the edge of a shrimp pond in Honduras help stabilize levees.*

Another application that can accrue from research on mangroves and shrimp farming is the selection of individual mangrove species for more effective planting programs for rehabilitation and mitigation purposes around shrimp farms. Installation of mangrove nurseries within shrimp farms is relatively cheap and could help advance ecophysiology studies that would in turn provide information for the selection of mangrove species.

Nursery and field studies can also offer information about the responses of mangroves to changes in nutrient availability and environmental stressors. This type of information is badly needed in mangrove ecology, particularly to forecast how human deforestation, eutrophication, and natural disturbances like hurricanes control the structure and function of mangrove forests at large spatial and temporal scales.

Because shrimp ponds are small ecosystems by definition, but impact the wider coastal ecosystems in which they are located, it is critical to consider the environmental context in which the shrimp industry is developed. Coastal regions around the world, particularly in tropical and subtropical areas, are strongly influenced by climatic events such as hurricanes and El Niño and La Niña events. Recent experiences in Central America have shown that the shrimp industry is extremely vulnerable to landscape-level disturbances, and its sustainability will depend on how the integrity of the environment is maintained to absorb or mitigate major disturbances.

Such climatic impacts have both direct effects and indirect effects related to major freshwater diversions or sediment redistribution in coastal areas. For example, although Hurricane Mitch did not hit the Gulf of Fonseca directly in 1998, its indirect effects were reflected in major diversions of the large Rio Choluteca and Rio Negro rivers, which control the hydrology of San Bernardo estuary, where large shrimp farms are located. It is only through the implementation of comprehensive, long-term monitoring that the actual consequences to the overall shrimp production (e.g., water quality, availability of wild shrimp larvae) of the Gulf of Fonseca region will be fully evaluated in the next decade.

The shrimp industry is strongly dependent on hydrological resources. Thus, it is critical that plans to assure the future sustainability of the industry take into consideration the connectivity and complexity of the ecosystems where shrimp farms operate. As this connectivity is not only related to ecological and biological aspects, but also social and cultural issues, the industry needs to play an active role in designing management plans and practices in which the conservation and rational use of mangroves resources become critical components.

The results of GAA's work and other recent initiatives, including a December 2000 FAO/Government of Australia Expert Consultation and the findings from the World Bank, NACA, WWF, and FAO Consortium on Shrimp Farming and the Environment provide a better understanding of the issues related to shrimp farming and coastal habitats, including mangroves. It is clear from these initiatives that better management practices can be adopted to eliminate the negative impacts of shrimp farming on mangroves and promote responsible farming in harmony with coastal environments. The challenge now is to take this understanding of better management practices and actively promote their widespread implementation. Education of shrimp farmers on the importance of mangrove conservation is critical to the promotion of better practices.

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# FEED INDUSTRY

## *Feed Additives*

GLOBAL AQUACULTURE ALLIANCE

# Feed Additives

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## Principles

The major components of a typical 35%-protein shrimp diet are wheat flour (35%), soybean meal (20%), and fishmeal (25%). These ingredients, along with other animal and plant meals, contribute most, if not all, of the protein, amino acids, and energy in the diet.

The remaining 20% of the formula is comprised of dozens of microingredients that help meet the nutritional requirements of shrimp not satisfied by major ingredients and serve a variety of other functions. In addition, additives serve as attractants, binders, preservatives, coloring agents, and health promoters.

The effectiveness of additives in feed pellets depends upon the concentration of their active ingredient(s), bioavailability (if nutrients), and physical properties such as water solubility, stability through the feed-manufacturing process, and leaching rate in the pelleted feed.

The net desired effects of additives should be estimated when deciding whether to use them. For example, additive products with poor thermal stability or high leaching rates provide poor economy in shrimp feeds, even though their cost per active ingredient may be lower than for improved product forms. Since additives almost always cost more per kilogram than macroingredients, they increase overall ingredient cost, requiring a corresponding improvement in feed efficiency or other desirable factors.

By far, the majority of additives used in pelleted shrimp feed are nutrients. Nutritive additives are used when principal feed ingredients do not contain optimum levels of required nutrients. Judicious use of additives improves feed efficiency by balancing the nutrient composition of the major ingredients, improving feed attractiveness, and enhancing pellet integrity.

## Survey

The Global Shrimp OP Survey section on Feed Additives addressed 110 additives thought to represent the most common ingredients used in shrimp feeds, but this list was not exhaustive. Over 2,500 food additives are registered by the United States Food and Drug Administration alone.

Feed additive vendors were invited to register the products they supply to the shrimp feed industry. For each additive, the survey questions requested recommended inclusion levels, current tonnage sold, current sales trends, and primary factors limiting use.

The 95 responses received were balanced almost equally between the Western Hemisphere and Eastern Hemisphere. Due to space limitations, this report focuses primarily on recommended inclusion levels and general observations and recommendations.

*Attractants help draw shrimp to feed and stimulate their consumption of the rations.*

### Attractants

Attractants contain water-soluble compounds of low molecular weight which stimulate feeding rates to increase feed efficiency and reduce feed waste in ponds. In addition, they improve the palatability of the vegetable proteins that are increasingly used in shrimp feeds.

Attractants draw the attention of shrimp either by stimulating the smell receptors located on the antennules, the taste receptors on the walking legs and mouth parts, or both. Two categories of attractants are used in shrimp feeds: animal by-products and purified compounds.

*Table 1. Respondents' use of crustacean meals as attractants.*

| | Crab Meal | Krill Meal | Shrimp Heads/ Shell Meal |
|---|---|---|---|
| Minimum inclusion rate | 2% | 1% | 3% |
| Median inclusion rate | 3% | 3% | 5% |
| Maximum inclusion rate | 3% | 10% | 15% |
| Annual ingredient sales (mt) | 3 | 700 | 1,000 |
| Estimated feed production with ingredient (mt/year) | 100 | 23,333 | 20,000 |
| Estimated percentage of global feed production | 0% | 1.2% | 1.0% |

***Animal by-product attractants.*** The animal by-product category includes crustacean meals, squid and squid by-products, low-molecular-weight fish extracts, and low-molecular-weight meat extracts. The range of addition of most of these additives is on the order of 3 to 5% of feed mass (Table 1).

Crustacean meals include crabs, shrimp heads or shell meal, and krill meal. Crab meal has the disadvantage of introducing undesirable calcium into the formula. Shrimp by-products pose the risk of disease transmission, although to date, shrimp viral disease has not been demonstrated in these products.

Krill is an excellent attractant and rich source of highly unsaturated fatty acids, but is generally quite expensive. All crustacean meals have high ash content (generally in excess of 20%), which limits their application in diet formulations.

Squid meal (Table 2) is a balanced source of protein and a documented shrimp growth promoter, but is expensive and poorly available. Squid liver powder is a product made from squid viscera and other inedible parts such as skins and fins. These are enzymatically hydrolyzed to form a broth, condensed in an evaporator, blended with a dry carrier such as soybean meal, and dried to a free-flowing form. It is a rich source of attractant compounds, and highly unsaturated fatty acids.

*Table 2. Respondents' use of by-products as attractants.*

| | Squid Liver Powder | Squid Meal | Fish Hydrolosates | Fish Solubles | Meat Solubles |
|---|---|---|---|---|---|
| Minimum | 1% | 1% | 2% | 2% | 1% |
| Median | 2% | 2% | 3% | 3% | 2% |
| Maximum | 3% | 3% | 5% | 5% | 3% |
| Annual sales (mt) | 400 | 700 | 3,460 | 3,440 | 40 |
| Annual feed production (mt) | 20,000 | 35,000 | 115,333 | 114,667 | 2,000 |
| % of global production | 1.0% | 1.8% | 5.8% | 5.7% | 0.1% |

Fish by-products include solubles and hydrolysates. Solubles refers to the condensed form of stickwater, which is the aqueous extract of cooked fish produced during fishmeal manufacturing. Solubles usually are sold as acid-stabilized, viscous liquids with 50% moisture,

*Although meal additives made from shrimp heads, squid, or other marine sources are effective attractants, their use can also bring disease concerns.*

although they can be dehydrated to dry forms. Hydrolysates are enzymatic digests of fish, which usually are spray-dried to powder form. Both products are rich in low-molecular-weight attractant compounds.

Meat solubles are produced from the aqueous extracts of cooked meat. These products usually are sold in spray-dried form. Like fish solubles, they are rich in attractant compounds. Although there is no evidence of BSE infection in shrimp, this could become an issue with meat and bone meals.

***Purified attractant compounds.*** Few survey responses were received on purified attractant compounds. The recommended inclusion levels based on this limited data are provided in Table 3.

*Table 3. Respondents' use of purified attractant compounds.*

| Attractant | Recommended Inclusion Level |
|---|---|
| Amino acids | 0.1% |
| Artificial flavors | No response |
| Betaine | 1% |
| Nucleotides | 90 ppm |

Free amino acids such as glycine, alanine, and glutamic acid are known attractants for many aquaculture species. Betaine and nucleotides such as inosine-5-monophosphate and guanosine-5-monophosphate are flavor enhancers for a variety of foods, including human snack foods. Some of these low-molecular-weight compounds appear to excite chemoreceptor neurons, but fail to produce positive chemotaxis and feeding activity.

In addition, a variety of artificial flavors comprised of cocktails of animal extracts and purified compounds are available for use in aquaculture feeds. As knowledge of chemoreception in shrimp improves, it is likely that high-potency purified attractants will be developed to substitute for or supplement animal by-products.

## ENZYMES

Hydrolytic endogenous enzyme supplements have come into widespread usage in terrestrial animal nutrition. The most common commercial enzyme preparations improve phytate and non-starch polysaccharide digestibility. Surveyed enzymes included alphagalactosidase, amylase, lipases, pentosanase, phytase, and protease. There is interest to use these additives in shrimp feed to improve nutrient utilization and reduce pond water deterioration.

Unfortunately, existing products have limited heat stability to survive feed manufacture, and surface coating of enzymes on finished shrimp feed presents leaching problems. Only one response was received for enzyme use in shrimp diets. The vendor indicated that all six of the surveyed enzyme categories are available in packs.

## GROWTH PROMOTERS

Additives such as antibiotics, coccidiostats, and hormones have been considered growth promoters in shrimp, but their commercial use is limited (Table 4).

*Table 4. Respondents' use of growth promoters.*

| | Isoflavones | Monensin | Nucleotides | Other Antibiotics |
|---|---|---|---|---|
| Minimum | 200 ppm | 0.1% | 1% | – |
| Median | – | 0.2% | 2% | 1% |
| Maximum | 500 ppm | 0.5% | 6% | – |
| Annual sales (mt) | – | 400 | 220 | 3,000 |
| Annual feed production (mt) | – | 200,000 | 11,000 | 300,000 |
| % of global production | – | 10.0% | 0.6% | 15.0% |

Long-term use of subtherapeutic levels of antibiotics may cause the development of antibiotic resistance in bacteria. This could result in difficulties treating humans infected with these antibiotic-resistant organisms. Scientific studies of this possibility have been inconclusive and heated debate continues. No vendors of antibiotic growth promoters responded to the survey.

Monensin is a coccidiostat, which prevents the infestation of parasites of the order Coccidia. It has been used as a treatment for gregarine parasites in shrimp and may be a growth promoter, as well. One respondent was selling monensin as a 20% premix. However, most major shrimp-importing countries such as the United States, Japan, and European Union countries do not permit the use of antibiotic growth promoters in consumed shrimp.

Isoflavones derived from soybeans are another potential growth promoter. The isoflavone dose recommended by the respondents was 200 to 500 ppm. Natural growth promoters include detrital matter, squid meal, and hormones.

## HEALTH ADDITIVES

***Immunostimulants.*** A variety of additives are being used to stimulate the immune systems of shrimp to increase their resistance to disease. Stimulation of phagocytosis activity and phenyloxidases, and enhancement of antioxidant activity are demonstrated mechanisms that have become important in reducing outbreaks of viral diseases such as White Spot Syndrome and as alternatives to antibiotic treatments. A list of these products and their recommended usage levels is given in Table 5.

*Table 5. Respondents' use of immunostimulants.*

| | Bacterial Extracts | Beta Glucans | | Mannanoligo-Saccharides | Seaweed By-products | Yeast |
|---|---|---|---|---|---|---|
| Minimum | 0.1% | 0.1% | 0.5% | 0.1% | 0.1% | 0.2% |
| Median | – | 0.5% | 2% | 0.2% | 0.5% | 2% |
| Maximum | 0.5% | 2% | 2% | 0.4% | 5% | 5% |
| Annual sales (mt) | – | 123 | 300 | 20 | 303 | 5,020 |
| Annual feed production (mt) | – | 24,600 | 15,000 | 10,000 | 60,600 | 251,000 |
| % of global production | – | 1.2% | 0.8% | 0.5% | 3.0% | 12.6% |

***Probiotics.*** Live cultures of beneficial bacteria are added to some culture systems to discourage colonization by pathogens. A similar approach has been adopted in some feeds, particularly larval diets. In growout feeds, heat-resistant spore-forming bacteria would be required to survive the feed-manufacturing process. One alternative is to surface coat finished feeds with living cultures. Respondents recommended inclusion levels of live bacterial cultures of 0.05 to 0.10%.

***Vaccines.*** The term "vaccine" is somewhat of a misnomer, because shrimp do not have a classic antigen-antibody system. Nevertheless, research has shown that shrimp immune systems have a short-term memory for certain antigens. Although a variety of shrimp vaccines are available, only one product, a deactivated bacterial material, was registered on the survey. Its recommended inclusion level was 1.0%.

## TOXIN ABSORBERS

Several additives are available to neutralize toxins in feed or water. One respondent recommended an additive to remove ammonia from the water when included in the feed at a level of 0.1 to 2.0 ppm.

Grains utilized in shrimp feed are often infected with fungus that can result in exposure of shrimp to mycotoxins. A variety of products are available to absorb mycotoxins to reduce their toxicity. Recommended inclusion levels were 0.1 to 0.5%.

## NUTRIENTS

***Lipids.*** The primary lipid additives for shrimp feed are essential fatty acids, phospholipids, emulsifiers, and cholesterol (Table 6).

*Table 6. Respondents' use of essential lipids.*

| | Cholesterol | Deoiled Lecithin | Fluid Lecithin | Phospho-lipids | *Schizo-chytrium* |
|---|---|---|---|---|---|
| Minimum | 0.1% | 0.5% | 0.5% | 0.6% | 0.5% |
| Median | 1% | 0.9% | 3% | 2% | 1% |
| Maximum | – | 5% | 8% | 3.7% | 4% |
| Annual sales (mt) | 170 | 320 | 6,150 | – | 20 |
| Annual feed production (mt) | 85,000 | 35,556 | 205,000 | – | 2,000 |
| % of global production | 4.25% | 1.8% | 10.3% | – | 0.1% |

This survey did not include sources of essential fatty acids such as fish oil and squid oil. The primary source of supplemental phospholipids for shrimp diets was lecithin, which is available in both fluid and deoiled forms. The recommended inclusion levels were 0.5 to 1.0% for deoiled and 1.0 to 2.0% for fluid lecithin.

Bile acids are a source of emulsifiers and cholesterol derived from rendering plants. The recommended inclusion level of this ingredient was 0.1%.

Cholesterol is an essential nutrient for shrimp. Although it is naturally present in feedstuffs such as fish oil, fishmeal, shrimp head meal, and squid by-products, it often must be supplemented to achieve sufficient levels in the diet. Respondents recommended a typical cholesterol inclusion level of 0.1%.

***Minerals.*** Shrimp diets generally are supplemented with phosphorus and a complete trace mineral premix. Respondents indicates typical mineral premix inclusion levels of less than 1% (Table 7).

*Table 7. Respondents' use of vitamin and mineral premixes.*

| | Mineral Premix | Vitamin Premix | Combination Premix |
|---|---|---|---|
| Minimum | 0.1% | 0.1% | 0.2% |
| Median | 0.4% | 0.25% | 0.2% |
| Maximum | 1% | 1% | 2.0% |
| Annual sales (mt) | 180 | 540 | 100 |
| Annual feed production (mt) | 45,000 | 216,000 | 50,000 |
| % of global production | 2% | 11% | 3% |

Some vendors offer organically bound minerals, which are more bioavailable, particularly for shrimp, which have no stomach acid. The source of mineral compounds affects bioavailability and the presence of heavy metal contamination.

***Vitamins.*** The recommended inclusion levels for vitamin premixes in shrimp diets ranged 0.1 to 0.5% (Table 7).

Vitamin C is lost quickly during storage and exposure to heat and moisture. Therefore it generally is added in a stable form such as the polyphosphate, monophosphate-Ca, monophosphate-Mg, or encapsulated ascorbic acid.

The phosphate derivatives protect the sensitive number 2 carbon by substitution with a phosphate molecule. The encapsulated forms protect crystalline ascorbic acid within a protective coating. Recommended inclusion levels for vitamin C were 150 to 2,000 ppm for encapsulated forms and 250 to 500 ppm for ascorbyl phosphate forms (Table 8).

*Table 8. Respondents' use of vitamin C forms.*

| | Encapsulated | Monophosphate |
|---|---|---|
| Minimum | 150 ppm | 250 ppm |
| Median | 400 ppm | 250 ppm |
| Maximum | 2,000 ppm | 500 ppm |
| Annual sales (mt) | 60 | 400 |
| Annual feed production (mt) | 150,000 | 1,600,000 |
| % of global production | 7.5% | 80% |

***Premixes.*** Premixes are blends which can include vitamins, minerals, amino acids, antioxidants, and other dry active constituents in a matrix of inert and non-water-absorbing components. The carrier supplies bulk and prevents interactions between the components. Both standardized and custom premixes are available.


*The more complete premixes include vitamins, minerals, and other additives, as well as a carrier.*

## PELLET BINDERS

Wheat flour is the dominant binder in shrimp feeds. However, it alone may not be adequate to provide proper water stability, particularly if the manufacturing process does not include fine grinding, extended conditioning, and post-pellet conditioning. Consequently, additional binders often are needed to assure water stability, especially in the West, where processing conditions may not be as sophisticated as in the East (Table 9).

*Table 9. Respondents' use of pellet binders.*

| | Lignin Sulfonate | Starch Binder | Wheat Gluten | Protein Binder | Urea Formaldehyde |
|---|---|---|---|---|---|
| Minimum | 0.5% | 5% | 3% | 5% | 0.3% |
| Median | 1% | 10% | 7% | 10% | 0.5% |
| Maximum | 1% | 15% | 10% | 15% | 0.8% |
| Annual sales (mt) | 4,000 | 5,000 | 12,000 | 3,000 | 3,100 |
| Annual feed production (mt) | 400,000 | 50,000 | 171,429 | 30,000 | 620,000 |
| % of global production | 20% | 2.5% | 8.6% | 1.5% | 31% |

Several categories of binders are used, including hydrocolloids, polymers, native proteins, pregelatinized starch, and wood derivatives. Inclusion levels for each binder recommended by respondents are listed in Table 10. Of these binder types, urea formaldehyde polymers, wheat gluten, and lignin sulfonate registered the greatest tonnage in terms of annual sales by respondents.

*Table 10. Respondents' use of hydrocolloid binders.*

| | Carrageenan | Guar Gum | Locust Bean Gum |
|---|---|---|---|
| Minimum | 0.2% | 0.5% | 0.5% |
| Median | 1% | 1% | 1% |
| Maximum | – | – | – |
| Annual sales (mt) | 5 | 400 | 5 |
| Annual feed production (mt) | 500 | 40,000 | 500 |
| % of global production | 0.0% | 2.0% | 0.0% |


*Various meals are the primary ingredients of shrimp feeds, but further additives enhance the final nutritional quality of the feed. Illustration by Jordan Chamberlain.*

## PIGMENTS

The pigmentation of shrimp is affected strongly by the levels of the carotenoid compounds in their diets. Certain markets, particularly in Japan, place a premium on shrimp with strong natural pigmentation. Ovarian pigmentation also is considered important for maximum reproductive performance of adults. Because typical feedstuffs in shrimp diets are devoid of pigments, additives can enhance pigmentation.

Carotenoids are naturally occurring compounds, the principal determinant of the intensity of shrimp pigmentation, and may be supplemented in the diet (Table 11). Astaxanthin is the most abundant naturally occurring carotenoid in marine shrimp and the most efficient source of pigmentation (Table 12).

*Table 11. Respondents' use of concentrated pigments.*

| | Canthaxanthin | Astaxanthin | Zeaxanthin | Beta-carotene |
|---|---|---|---|---|
| Minimum | 60 ppm | 15 ppm | 80 ppm | 50 ppm |
| Median | 80 ppm | 50 ppm | 80 ppm | 75 ppm |
| Maximum | 90 ppm | – | 120 ppm | 100 ppm |
| Annual sales (mt) | 3.0 | 0.3 | 1.0 | 0.1 |
| Annual feed production (mt) | 37,500 | 6,000 | 12,500 | 1,333 |
| % of global production | 2% | 0.3% | 0.6% | 0.1% |

*Table 12. Respondents' use of plant product pigments.*

| | Astaxanthin From Yeast | Marigold Meal | Paprika | Spirulina | Astaxanthin From *Hematococcus* |
|---|---|---|---|---|---|
| Minimum | 50 ppm | 80 ppm | 0.5% | 80 ppm | 40 ppm |
| Median | 75 ppm | 90 ppm | 1% | 100 ppm | 40 ppm |
| Maximum | 100 ppm | 120 ppm | 3% | 150 ppm | – |
| Annual sales (mt) | 0.1 | 0.15 | 2 | 0.4 | 0.2 |
| Annual feed production (mt) | 1,333 | 1,667 | 5,000 | 4,000 | 5,000 |
| % of global production | 0.1% | 0.1% | 0.3% | 0.2% | 0.3% |

Shrimp have the biosynthetic capacity to convert some other pigments to astaxanthin, such as beta-carotene and canthaxanthin, although with reduced bioavailability. In addition to serving a role in pigmentation, certain carotenoids have been shown to possess biological roles in shrimp metabolism in reproduction and immune response. Unpurified plant pigments also are used to improve shrimp coloration.

## ANTIOXIDANTS AND PRESERVATIVES

Shrimp feeds often are stored for several weeks in hot, humid tropical environments. To prevent oxidation of fats and mold infestation, antioxidants and preservatives generally are added.

***Antioxidants.*** The most common antioxidants for use in animal feeds are butylated hydroxytoluene (BHT), butylated hydroxyanisole (BHA), and ethoxyquin. Respondents indicated that the recommended inclusion level of ethoxyquin is 125 ppm. The recommended inclusion level for other antioxidants was given as 250 to 500 ppm.

***Mold inhibitors.*** Most mold inhibitors are sodium or potassium salts of propionic, benzoic, or sorbic acid. Recommended inclusion levels for these compounds were 0.05 to 0.15%.

*Shrimp have specialized digestive tracts and feeding habits that call for feed with high water stability.*

## Recommendations

A wide variety of additives are used in shrimp feed. These include attractants, enzymes, growth promoters, health additives, toxin absorbers, lipids, vitamins, minerals, pellet binders, pigments, antioxidants, and preservatives. The Global Shrimp OP: 2001 survey generated valuable information about sources of these additives, their recommended inclusion levels, and factors limiting their usage.

Farmed shrimp farm-gate value now exceeds U.S. $6 billion. This value is sufficient to merit specialized product forms, and some additive buyers have requested specialized forms.

Shrimp have specialized digestive tract and feeding habits that are not well suited for conventional sources. Shrimp have digestive tracts that are only two-thirds of their body length. The tracts fragment feed particles upon consumption. Shrimp do not have acidic digestive fluids in their stomachs. Shrimp are slow grazers, and feed pellets with high water stability are essential for efficient feed use.

The rapid growth of aquaculture is leading to increasing use of expensive and limited supplies of marine proteins and oils. To reduce feed costs and assure sufficient supplies of marine proteins, greater substitution of fishmeal, fish oil, squid products, and crustacean products is needed. Attractants, micronutrients, and enzymes may be especially important in replacing marine proteins with vegetable proteins.

Shrimp feed is the principal organic input in shrimp culture. Therefore, it is the principal source of potential contaminants. Full traceability and quality control is needed for all ingredients comprising shrimp feed.

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# FEED INDUSTRY

# *Feed Manufacturing*

GLOBAL AQUACULTURE ALLIANCE

# Feed Manufacturing

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## Principles

The rapid growth of shrimp farming led some well-established producers of farm animal feeds into the production of shrimp feeds. Also, as a result of the rising costs of feed and lower shrimp prices, shrimp farmers are trying to reduce production costs and add value to their products. This has resulted in greater vertical integration that includes processing plants and hatcheries, and ultimately feed mills, because feed accounts for up to 60% of direct operating costs.

Over 3 million metric tons of shrimp feeds are produced worldwide. Approximately 80% is produced in the Eastern Hemisphere and the rest in the Western Hemisphere.

Production of shrimp feeds represents a significant change for traditional farm animal feed mills. It involves adapting facilities, changing equipment, and learning new processing methods to produce high-quality, water-stable feeds. A major hurdle for most traditional feed mills is the acceptance of low throughputs and the challenge of producing feeds that maintain their physical integrity in water for an extended time.

*Specialized aquaculture feeds are manufactured in a variety of configurations to meet the nutritional needs of the target species.*

Consistent production of water-stable feeds requires an understanding of the influences of ingredients and processing factors such as particle size, steam preconditioning effects on starch gelatinization, pelleting die compression ratios, extrusion processing, and postpellet conditioning.

### GRINDING REQUIREMENTS

Specialized shrimp feed mills are distinguished from traditional farm animal feed mills in the grinding operation. Shrimp feeds require particle sizes no larger than 250 microns, and for smaller shrimp, 150 to 180 microns. In contrast, porcine and poultry animal feeds require particle sizes of 500 microns or larger.

In traditional feed mills, hammermills operate at 1,800 rpm. In contrast, hammermills for shrimp feed operate at 3,600 rpm or more to achieve very fine particles. In most cases, desired particle sizes are achieved with two hammermills in series and a screener to recirculate larger particles to the second unit. To control dust from fine grinding, feed mills include special filter bag houses and hermetically designed conveying systems to reduce shrink losses from dust emissions.

Particle size reduction improves feed efficiency by increasing the surface area of the feed ingredients. This increases the area of ingredients for action by the animals' digestive systems, and enhances digestion and feed conversion. Particle reduction is particularly important for shrimp, because their short digestive tracts and high rates of food passage reduce the efficiency of nutrient adsorption.

Particle size reduction also is important in mixing, pelleting, and extrusion. Efficient grinding and mixing maximize the homogeneity of the final feed. Moreover, particle size reduction has an important role in shrimp feed water stability. Smaller particles have more surface area to absorb moisture and heat during preconditioning, which is necessary to activate natural binding agents such as starch, proteinaceous materials, and gluten. Larger surface area also allows more contact points between particles and reduces voids when the meal is subjected to high pressures in the forming die during pelleting.

*As shown in this magnified shrimp feed pellet, uneven particle sizes accentuate microscopic cracks that degrade feed performance in water.*

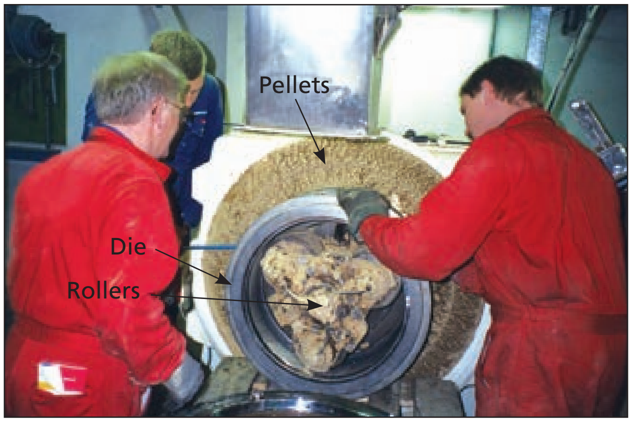
Compaction forms a tight structure that prevents water penetration and improves the water stability of the feed. Larger particles produce pellets with voids, cracks, and rough surfaces that allow water to penetrate and cause disintegration before shrimp have a chance to consume the feed. Uneaten feed leads to poor feed conversion. It also accumulates on pond bottoms and causes soil and water quality problems.

## POSTGRINDING

Aquatic feed mills depend more on postgrinding systems than traditional pregrinding systems used for other farm animal feeds. In traditional mills, major ingredients are passed through the grinding center before being weighed and mixed. Conversely, in aquatic feed mills, ingredients are passed through the grinding center after being weighed and mixed.

The reason for postgrinding in aquatic feeds is the inclusion of difficult-to-grind ingredients such as fishmeal. Premixing dilutes the negative effects of such ingredients and produces more uniform particle size distribution. The ground meal of target particle size is passed to a second mixer, where all other minor ingredients such as heat-labile vitamins, encapsulated vitamins, and liquids are added. From the mixer, the formula meal is sent to the compounding center.

Another major difference between traditional and aquatic feed mills can be found in the pelleting center. Pellet mills in traditional mills use shorter residence times of 10 to 60 seconds for preconditioning, compared to preconditioning times of at least two minutes in shrimp feed mills.




*The open door on this pellet mill reveals the donut-shaped die bristling with pellets and the rollers inside.*

Pelleting dies used to produce shrimp feeds compress the mixed feed ingredients as they pass through the channels of the die. The compression ratio is the diameter of the die bore divided by the effective length of travel. Shrimp feeds require compression ratios of 20 to 24, while poultry and swine feeds require compression ratios of 10 to 12.

The higher compression for shrimp feeds is required to produce water-stable pellets with a minimum percentage of fines. As compression increases and open area in the die decreases, production capacity decreases. A pellet mill sized to produce 30 metric tons per hour of poultry feed may produce only four to five tons of shrimp feed.

Postconditioning or pellet curing are similar terms describing the process of keeping pellets warm after passage through the pellet mill. Postconditioning – another key difference between shrimp feeds and terrestrial animal feeds – improves water stability by 30 to 40% without including expensive synthetic binders.

In addition, the degree of starch gelatinization depends on time and temperature. Thus, postconditioning provides for further cooking starches, which in turn improves water stability. Postconditioning improves water stability because the pellets are not subjected to a sudden change in temperature from the cold draft of the cooler.

Sudden contraction from rapid cooling causes microscopic cracks which are avenues for water penetration into pellets. In contrast, slow cooling during postconditioning allows slow contraction and permits particles to come together in a tighter structure than with sudden cooling.

*The screw sections in extruders are designed with variable pitch and depth to apply mechanical energy to cook the moist meal through heat, pressure, and shear.*

## EXTRUSION

Another device used to manufacture shrimp feeds is the extruder. The extrusion process applies mechanical energy by screws that shear the moist meal and increase its temperature and pressure. As the meal moves toward the die, pressure and density increase and viscosity decreases, resulting in an amorphous extrudate melt.

Extruders do an outstanding job of thoroughly cooking meal and gelatinizing starch. Typically, the high pressures within extruders cause expansion of the meal as it exits the die, which results in pellets that float.

Flotation can be reduced but not eliminated by formulation changes such as reducing starch content and increasing moisture and fat content.

To completely eliminate flotation, extruded shrimp feeds usually are made in a two-step process with cooking/expansion followed by forming/compression. These processes can be accomplished by using two extruders mounted in series, an expander followed by a pellet mill, or a sophisticated single extruder configured with separate cooking and forming zones.

Another issue affecting extrusion processing is the amount of work applied to an extruded meal, as measured in kW·h/MT of specific mechanical energy (SME). Excessive shear within extruders causes starch molecules to break into smaller fragments (dextrinization). Although this process can improve starch digestibility, it results in more-soluble feeds that rapidly absorb water and disintegrate more quickly. Extrusion of shrimp feed is best accomplished at low SME to avoid excessive starch dextrinization.

# Survey

The Feed Manufacturing section of the Global Shrimp OP: 2001 Survey sought information about grinding, preconditioning, pelleting, extrusion, postconditioning, fat coating, and methodology for assessing water stability. There were 37 respondents: 20 from the Western Hemisphere and 17 from the Eastern Hemisphere. Several countries were represented in both hemispheres (Table 1).

*Table 1. Geographic distribution of manufacturer respondents.*

| Eastern Hemisphere | Respondents | Western Hemisphere | Respondents |
|---|---|---|---|
| Belgium | 1 | Belize | 1 |
| China | 1 | Brazil | 1 |
| India | 2 | Ecuador | 2 |
| Indonesia | 1 | Guatemala | 1 |
| Japan | 1 | Mexico | 1 |
| Malaysia | 2 | Panama | 1 |
| Netherlands | 1 | United States | 12 |
| Philippines | 1 | Venezuela | 1 |
| South Korea | 1 | | |
| South Africa | 1 | | |
| Taiwan | 2 | | |
| Thailand | 2 | | |

## FEED FORMULATION

More than 50% of the respondents from the East used least-cost formulation as compared to only 28% in the West (Figure 1). Sixty-three percent of the Eastern respondents formulated based on digestible nutrients as compared to only 41% in the West.

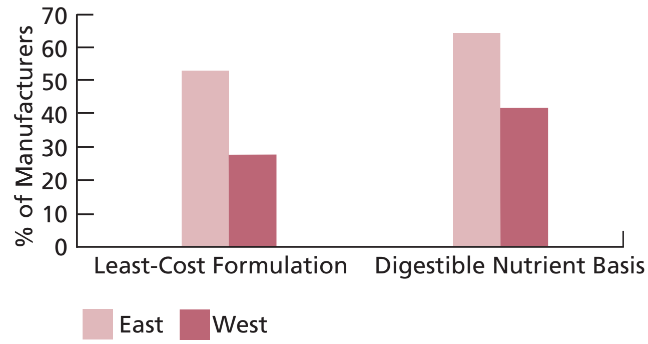



*Figure 1. Methods of formulation used by participating shrimp feed manufacturers.*

## PROCESSING

***Grinding.*** The equipment most commonly used for particle size reduction was the hammermill. Hammermills were used by 54% of the respondents in the East and 35% of respondents in the West (Figure 2). However, the Eastern producers used pulverizers almost as much as hammermills (54 and 48%, respectively). In the West, only 17% of the respondents used pulverizers, which meant that hammermills were used more than twice as frequently as pulverizers.

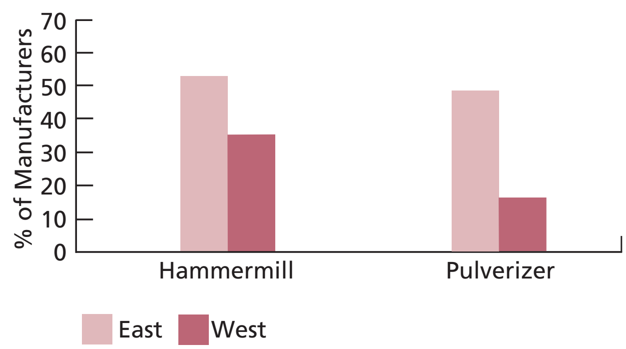



*Figure 2. Grinding methods used by feed producers.*

*This open hammermill shows the screen installed on the left, and removed on the right to expose articulating hammers.*

***Preconditioning.*** In the East, 42% of respondents used extended preconditioning, in contrast to 33% using standard preconditioning (Figure 3). In the West, however, only 21% of respondents used extended preconditioning. It is well known that shrimp feed producers in the East have used extended preconditioning for more than a decade as a standard method to produce water-stable feed. The East reported no use of expanders to precondition or gelatinize mash prior to compounding, while 10% of the Western respondents used expanders.

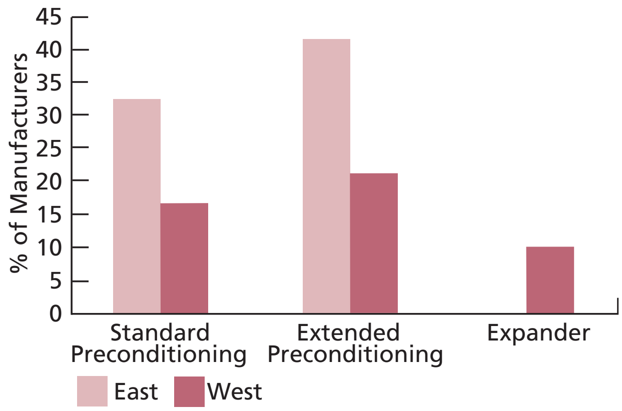



*Figure 3. Methods of preconditioning used by respondents.*

Expander technology has been used extensively in Europe to improve the starch gelatinization of feeds for poultry, swine, and cattle, and to some extent, aquatic feeds. Very few expanders are used today in the production of shrimp feeds, owing to their high cost of energy and high level of starch dextrinization. The latter is caused by excessive mechanical energy that chops starch into smaller glucose fractions (dextrins). These fractions are very soluble in water and reduce water stability considerably.

***Pelleting, extrusion, fat coating.*** The preferred method of compounding in both hemispheres was the pelleting process. According to the survey, 67% of the pellet-forming process in the East was accomplished with pellet mills and 33% with extruders (Figure 4). In the West, 35% of respondents used pelleting and 21% used extrusion. The differences between the two regions could be attributed to the lower manufacturing costs and technical expertise that pelleting requires in comparison to extrusion.


*Figure 4. Compounding methods used by shrimp feed producers.*

Controlling shear rate is difficult in extrusion processing, which utilizes more energy and leads to higher manufacturing costs. The initial capital investment for an extrusion line can be three times greater than for a pellet mill. The justification for using the extrusion process is to reduce raw material costs by facilitating lower inclusion of less expensive starch binders than traditional wheat flour used in the pelleting process.

Another advantage of the low-shear extrusion process is the production of sterile feeds. Under the temperature, pressure, and shear to which meal is subjected in an extruder, pathogenic organisms including viruses are virtually eliminated. This is an important advantage if the manufacturer is using marine by-product meals that are potential carriers of pathogenic organisms such as White Spot Syndrome and Taura Viruses.

In the West, 28% of respondents reported the application of fat to feed pellets, as compared to fat use by only 8% of respondents from the East. This could be attributed to differences in the energy and fatty acid requirements of the shrimp species to which the feed was offered. Another possible explanation is the higher inclusion of fishmeal or other marine meals high in lipids, omega-3 fatty acids, and total energy in feeds for *Penaeus monodon* in the East. These feeds require less oil for top dressing after pelleting.

In the West, where *L. vannamei* is the dominant species, the opposite is true. Shrimp feed formulas in the West have less fishmeal and more soybean meal. Therefore, formulas need to be balanced to meet energy and long-chain, free fatty acid requirements. The latter can be accomplished by top dressing pellets with fish oil after drying and cooling.

*This postpellet conditioner uses a moving belt within a horizontal steam chamber.*

***Postpellet conditioning.*** Postpellet conditioning is the process of holding feed pellets after they exit the die in a bin, hopper, or slow-moving horizontal conveyor. Some equipment manufacturers have developed postpellet conditioning units maintained at a constant temperature with direct steam addition to increase pellet moisture during curing. Whatever equipment is used to postcondition the pellets, the objective is to increase the water stability of the feed.

About 54% of the Eastern respondents used postpellet conditioners, as compared to only 17% in the West (Figure 5). The latter correlates with 31% of the responses from the West that expressed the need for more research with binders to improve the cost effectiveness of shrimp feeds, whereas no farms in the East shared that view.

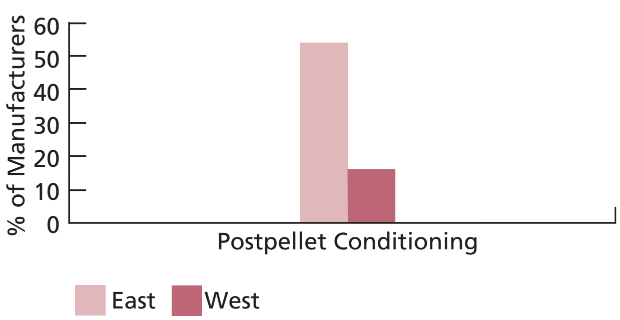



*Figure 5. Shrimp feed mills that used postpellet conditioning and fat coating.*

## WATER STABILITY

The water stability method of choice for both hemispheres was immersion and visual observation (62 and 34% for East and West, respectively). Immersion, agitation, and drying were second in popularity (21 and 17% for East and West, respectively). In the East, 12% of the respondents also used the hardness test, in contrast to the West, where this method was apparently not used. Only 11% of the respondents measured the hydration percentage of the pellets after immersion. However, 93% of respondents in both hemispheres said that water stability tests should be standardized.

A standard method for measuring water stability should be easy to conduct and require no more than an hour to complete. It should be quantifiable, repeatable, and precise. A standard method would allow the industry to communicate in common terms and allow better guidelines for pellet quality to be developed.

*Water stability tests are ideally based on standardized immersion, agitation, and drying techniques.*

## FISHMEAL

Fishmeal use in shrimp feeds has drawn scrutiny from conservation groups over the past decade due to concerns that increasing use may not be sustainable. Fishmeal is a primary protein source in shrimp feeds in both the East and West. The data for the East indicated that only 44% of those surveyed reduced the inclusion of fishmeal in their formulation. In the West, 52% of respondents reduced the inclusion of fishmeal. This can probably be attributed to differences in the protein requirements of the somewhat regionalized primary species preferences.

## RESEARCH NEEDS

Respondents were asked to prioritize research and technology needs for more cost-effective formulas for shrimp feeds. For the East, the ingredients and additives were categorized in the following order: amino acids (56%), growth promoters (19%), enzymes (13%), and immunostimulants and attractants (6%). Fishmeal replacements, encapsulation to reduce leaching, fatty acids, cholesterol, pellet binders, minerals, phospholipids, vitamins, antibiotics, and pigments were not selected.

In contrast, the second priority selection yielded the following results: phospholipids (11%); fatty acids (10%); cholesterol, pellet binders, and minerals (8%); enzymes, growth promoters, and immunostimulants (7%); attractants (6%); vitamins and pigments (5%); amino acids (3%); and fishmeal replacements and antibiotics (2%).

The West had similar top priorities – 31% of the respondents indicated that amino acids were the highest priority. However, the same proportion of respondents also indicated that pellet binders were of crucial importance for the improvement of their feeds. The latter contrasts with the Eastern Hemisphere, where pellet binders were considered only a second priority. This could be attributed to the specialized fine grinding, preconditioning, and postconditioning processing methods more commonly used in the East.

At 13%, fatty acid research was second to research on amino acids and pellet binders in the West, which contrasted with the East, where the survey indicated fatty acid research was a second priority. In the West, attractants, growth promoters, minerals, and pigments each received 6% of the responses for first research priority.

At 14%, attractants were indicated as the top second priority for respondents from the Western Hemisphere. Amino acids came in at 9%, followed by encapsulation, immunostimulants, and fatty acids at 8% each, and cholesterol at 7%. Enzymes, minerals, fishmeal, and antibiotics were of the least interest.

In conclusion, the major overlaps of interest in both hemispheres were in amino acids and growth promoters. The greatest differences were in pellet binders, minerals, pigments, and fatty acids. These differences could be attributed to differences in nutritional requirements between major species and/or processing differences.

### SPECIAL FEEDS

Relative to the manufacturing of special feeds for intensive systems with low water exchange, only 48% of the respondents in the East produced special feeds for this purpose. In contrast, 75% of the Western respondents indicated that they provide special feeds for these intensive systems.

## Recommendations

### INGREDIENTS

Quality feeds can only be produced with quality raw materials. It is critical to know the benefits of each ingredient and how each ingredient affects the nutritional and physical quality of the shrimp feed.

To improve water stability, pelleted feeds should include a minimum of 20% starch from cereal grains such as corn, wheat, and rice, or tubers such as cassava. Wheat is a good source of starch and protein. The protein in wheat gluten is recognized as the best natural binder for improving water stability.

However, too much starch in a formula can cause problems in the pelleting process, because starch increases friction in the die and can result in clogging. To reduce friction, it is necessary to include a lubricant such as oil in the formula. When this is done, the nutritionist must take into account the energy:protein ratio to maintain proper balance.

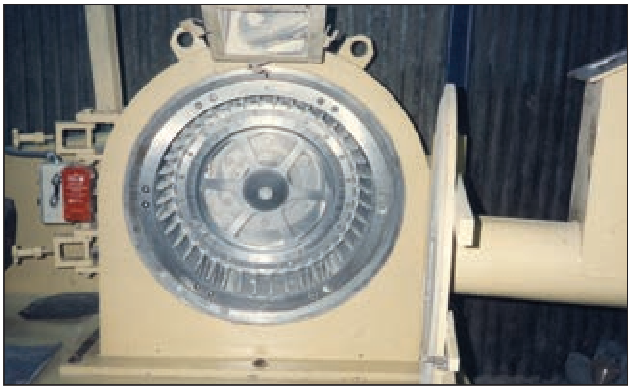
### PROCESSING

***Grinding.*** In shrimp feeds, it is necessary to reduce the particle size of ingredients. For adequate water stability and feed conversion in growout feeds, a particle size of 250 microns, or a maximum 5% retained on a 60-mesh Tyler screen, is generally recommended. For larval feeds, particle size should be 170 to 180 microns, or a maximum 5% retained on an 80-mesh screen. The particle size of the meal also directly relates to the diameter of the pellet produced. With pellet diameters as small as 1.6 millimeters, particles should not be larger than 200 microns in diameter.

Particle sizes larger than recommended for the die diameter can reduce the efficiency of the pelleting press. This is because the pellet mill would work as a grinder rather than a forming press, reducing its efficiency. Also, larger particles create stress points in pellets, which can increase fines and further reduce the pellet efficiency and overall pellet quality. Larger particles produce structures with more open spaces, which become avenues for water penetration to reduce water stability and feed conversion.

In hammermills, which consist of a rotor assembly with two or more rotor plates fixed to a main shaft, particle size reduction results from impacts between the rapidly moving hammer and the incoming material, and impacts between particles and against the screen. In most aquaculture feed operations, two or more hammermills are used in sequence to achieve particle sizes of 250 microns or less.

Hammermills are only efficient in grinding particles down to 300 microns. To achieve the smaller sizes requires a grinding circuit with sifters in between to recycle coarser particles back to the hammermill for further grinding. The latter can become an inefficient process, particularly with materials that are difficult to grind.



*This view of a pulverizer shows its high-speed rotor.*

Pulverizers are the most common choice when the particle size must be below 200 microns. This type of mill is capable of reducing particles to 100 microns because the hammers rotate at higher tip speeds than in hammermills. They also use air to control the particle sizes and have no screens to clog. Their main disadvantage is high initial cost.

Grinding accounts for up to 60% of the costs of feed manufacturing. Its cost includes both energy use and losses because of fines. Whatever equipment is used, it is very important to include bag filters to collect dust. Most importantly, locate the grinding center in an open area to prevent dust explosions.

***Mixing.*** The mixing process is the heart of the feed mill, where all the ingredients are assembled to meet the nutritional requirements of the target animal. The objective of the mixing process is to produce a homogeneous blend in which any sample taken from the mixer is identical in nutrient composition to any other sample. Improper mixing can result in reduced growth rate, high mortality, and high feed-conversion ratios in shrimp.

The following guidelines can help insure uniform ingredient mixing:

- One of the most important physical properties that affect mixing quality is ingredient particle size. Very small and large particles do not mix well because the small, dense particles segregate to the bottom of the mixer, while larger, less-dense particles stay at the top. To achieve homogeneous particle size and adequate mixing, all major ingredients should be ground together before mixing.
- Mixers should be cleaned frequently to avoid build-up on paddles or ribbons, which reduces mixing efficiency. Worn paddles or ribbons reduce efficiency because the clearance between the tips of the ribbons or paddles and the walls of the mixer increases. When this happens, the mixing action is reduced and heavy, fine material cannot be incorporated in the mixer. Also, gates should shut tightly to prevent particles from leaking out.
- Mixers should be tested at least every six months to determine if they are mixing homogeneously. The standard in the feed industry is a coefficient of variation (mean divided by the standard deviation) of less than 10%.
- The order in which ingredients are added to the mixer can affect mixing efficiency. The sequence of ingredient addition depends on the formulation, type of ingredients, and activation of natural or synthetic binders. Of particular importance is the time when binders are added to the mix.

In most cases, binding agents need to be activated by water and later in the pelleting process by temperature. However, if a binder is coated in the mixer with a hydrophobic liquid such as oil or lecithin, it will not absorb water readily and fail to develop its binding properties. This can reduce the water stability of the pelleted feed.

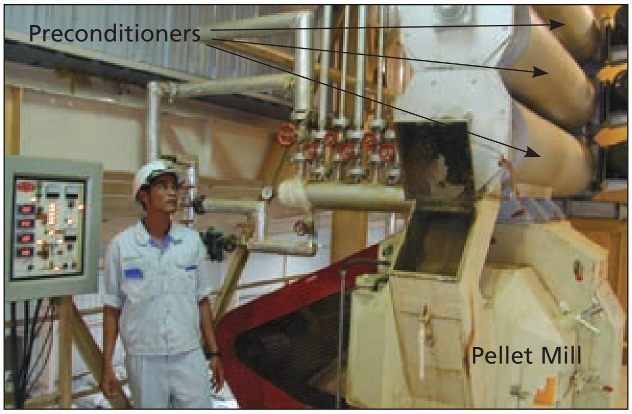
Aquaculture feed ingredients should be added to the mixer in the following order: First, all major ingredients from largest to smallest – e.g., fishmeal, soybean meal, cereal flours, etc. Then minor ingredients such as trace elements, vitamin premixes, and cholesterol from largest to smallest. A dry mixing time should be allowed before the addition of liquid ingredients.

Liquid ingredients must be sprayed, not poured, onto the mash to prevent clump formation. The first liquid added should be water because it must be absorbed by the particles to improve binding capacity in the pelleting or extrusion process. Lipids should be added last to prevent coating the particles and inhibiting the hydration of the starch and other binding agents. After all liquids ingredients are added, allow time for further wet mixing to ensure adequate dispersion throughout the mix.

***Preconditioning.*** Steam added in the preconditioning process should be of low pressure (2 bar). Steam transfers its thermal energy as it condenses on the surface of the cooler feed particles. It takes time for the moisture and heat to penetrate, so mash should stay in the preconditioner at least two minutes and preferably three minutes, depending on the initial moisture and temperature of the meal.

If the moisture in the mash is high and the temperature low, excessive dwell time in the preconditioning can result in a mash with high moisture concentration. Overly moist mash causes the rollers to slip and eventually clogs the die. Moisture content in material exiting the die should be 16 to 17% at 90 to 100 degrees C.

As a rule of thumb, for each 10-degree C rise in mash temperature, 1% of moisture is added. Therefore, if the mash moisture entering the preconditioner is at 12% and 40 degrees, it would require elevating the moisture concentration by five 1% units to achieve 17%. A 5% rise in moisture level is equivalent to a 50-degree increase in temperature or a final mash temperature of approximately 90 degrees.




*Multiple preconditioners are positioned above this pellet mill to moisten and heat meal with steam before it reaches the pellet mill.*

***Pelleting.*** Dies should be constructed of corrosion-resistant material such as high-chrome, stainless steel with a low coefficient of friction. The dies should have as much open area as possible to ensure the highest capacity. The compression ratio (total effective thickness divided by orifice diameter) for shrimp feed dies should be at least 20. For dies of 2.2-millimeter orifice diameter, the total effective thickness should be at least 44 millimeters. As the orifice diameter is decreased, the thickness of the die is reduced to compensate for the compression ratio. If the die is too thin, it can break. Therefore, some die manufacturers reduce the amount of open area to increase the strength of the die, but this also reduces die capacity.

The following suggestions related to die maintenance should be followed:

- Each die should have two pairs of rollers. These should to be changed at half the life of the die.
- After finishing each run or before shutting down the pellet mill, it is important to purge the die with an oily mix such as soybeans. By no means should a die be left with feed residue, because this can cause blockage and difficult start-ups the next time it is used.
- Die wear needs to be monitored using tools provided by the die manufacturer. As dies wear down, compression ratio is affected. Excessive die wear negatively effects pellet durability and water stability.

To compensate for die wear, throughput should be reduced to the point that pellet durability and water stability are maintained. However, it is better to replace the die, when the quality of the feed is at risk.

***Postconditioning.*** It usually is recommended to postcondition shrimp feeds for at least 10 minutes at 90 degrees C. However, this process should be optimized by cooperation between the process engineer, production manager, and operator. Optimization should take into account factors such as preconditioner meal temperature and moisture, pellet mill capacity, pellet moisture and temperature exiting the die or entering the postconditioner, dwell time in the postconditioner, and final pellet temperature.

During process optimization, physical pellet parameters such as water stability, pellet hardness, and percent fines should be measured for each of the changes made to achieve optimization. More sophisticated analysis, such as starch gelatinization and correlation analysis between factors, can determine the most controllable factors to provide the best possible processing conditions for the highest quality and capacity. Formula changes also can affect pellet quality and processing conditions.

*Gentle handling of feeds is important at all stages from manufacturing to bagging and final distribution.*

Finished pellets should be handled gently to avoid damage that can produce cracks or fines and lead to poor water stability. It is recommended to reduce free fall between equipment units as much as possible and reduce the speed at which the pellets fall in spouts. Preference should be given to drag conveyors over screw conveyors to reduce product breakage. Bucket elevator speeds should be as low as possible to avoid catapulting finished feed against the exit walls.

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# DIAGNOSTICS

## *Lab Procedures And Services*

GLOBAL AQUACULTURE ALLIANCE

# Lab Procedures And Services

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## Principles

Because the social and economic impacts of White Spot Syndrome Virus (WSSV), Taura Syndrome Virus (TSV), and other pathogens have been severe, the shrimp-farming industry has sought ways to restore production levels to the "previrus" years. This led the industry to realize that effective pathogen detection, disease diagnosis, and biosecurity are essential elements in gaining greater understanding of diseases and ways to prevent or manage losses from them.

The purpose of the Lab Procedures and Services section of the Global Shrimp OP Survey was to determine the current world status of diagnostic infrastructure for shrimp farming and measure interest for a centralized laboratory accreditation program. Results from this survey indicated some differences in the diagnostic capabilities and services provided in the Eastern and Western Hemispheres.

## Survey

### LABORATORY CHARACTERISTICS

Only a decade ago, there were just a handful of shrimp disease diagnostic laboratories worldwide. Currently, there are at least 40 such labs in the Western Hemisphere, and up to four times as many in the Eastern Hemisphere. Of these, a total of 55 responded to the GAA online survey. Although the response was too small to give a strong representation of current global status, it did indicate general trends.

Twice as many responses were received from the West than the East (Table 1). The United States, Mexico, and Ecuador accounted for 70% of the responses from the West, with Thailand and India accounting for 56% of the responses from the East.

*Table 1. Geographic distribution of survey respondents.*

| East | | West | |
|---|---|---|---|
| | No. of Responses | | No. of Responses |
| Australia | 2 | Brazil | 1 |
| India | 5 | Colombia | 2 |
| Indonesia | 1 | Costa Rica | 1 |
| Philippines | 1 | Ecuador | 6 |
| Taiwan | 2 | Guatemala | 2 |
| Thailand | 5 | Honduras | 2 |
| Sri Lanka | 1 | Mexico | 7 |
| Malaysia | 1 | Nicaragua | 1 |
| | | Panama | 2 |
| | | USA | 13 |
| Totals | 18 | | 37 |

For both hemispheres, the government and research laboratories that provide service to the industry via cost recovery were dominant (about 60% overall). There were proportionally more for-profit commercial labs in the East, but more farm-owned laboratories in the West (Figure 1). None of the respondents indicated private lab ownership as part of a local association, as is seen in other farming or livestock industries.

*Production losses to White Spot Syndrome Virus and other diseases spurred a greater need for diagnostic labs.*

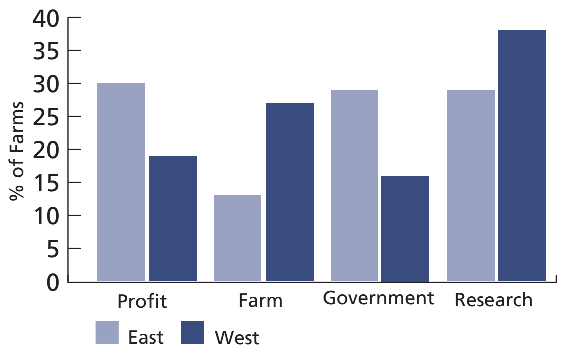


*Figure 1. Types of diagnostic laboratories. There were more for-profit laboratories and fewer farm laboratories from the Eastern Hemisphere.*

The survey indicated that for both East and West, the laboratories processed large numbers of specimens, typically 500 to 10,000 per year (Figure 2). Of the responding facilities, the predominance comprised small operations with one to five staff members, but several laboratories reported 10 or more staff.

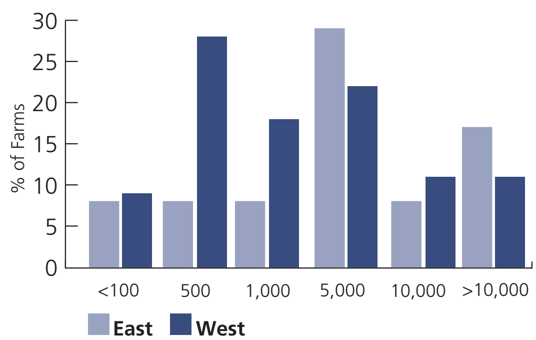


*Figure 2. Number of specimens processed annually.*

*PCR testing was frequently used by responding labs from both hemispheres.*

## LABORATORY PROCEDURES

Regarding diagnostic capabilities, 94% of the laboratories from the West carried out histological analyses using paraffin-embedded tissues, while only 72% of Eastern labs did (Figure 3). The reasons for this difference were unclear.

Laboratories in both hemispheres tended to do antibiograms with commercially available disks and in-media minimum inhibitory concentration testing, although these tests were more frequently used in the West (94%) than the East.

Capabilities for bacterial identification were similar in the East and West, at about 70% overall. These tests were accomplished using classical tube methods, API and Biolog systems, BBL Crystal, NF/E, VITEK, and molecular methods. About 41% of the Western respondents used kits, compared to 21% kit use in the East.

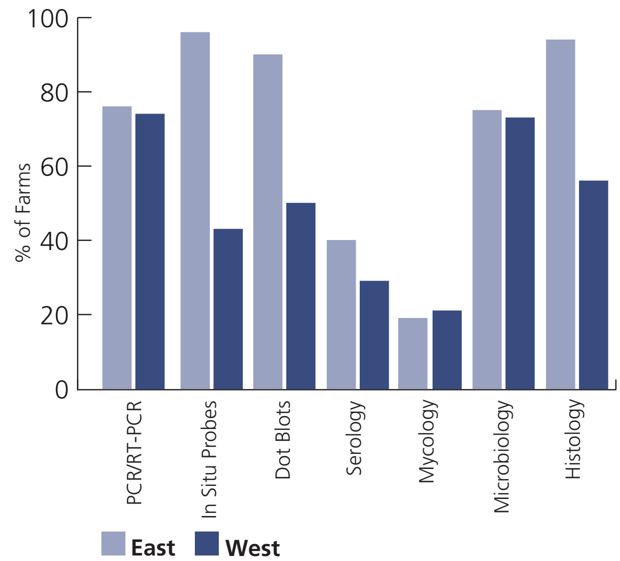


*Figure 3. Types of procedures performed.*

Only 19% of the laboratories from the West and 21% from the East provided fungal isolation and identification services, suggesting a rather low level of concern about fungal diseases. Responses regarding the use of tissue culture techniques were also very low from both hemispheres, reflecting the limited use of primary cell cultures in routine diagnostics. This technology remains largely in the research and development phase as a diagnostic tool.

Antibody-based serological techniques such as immunohistochemistry and ELISA tests were used by approximately 40% of the Western laboratories and fewer from the East.

Immunohistochemistry was used more frequently than FA, IFA, IFAT, and ELISA in both hemispheres, with tests for WSSV, Yellow Head Virus (YHV), and TSV dominating (Figure 4). Not surprisingly, 24% of the Eastern Hemisphere laboratories indicated they used immunohistochemistry for YHV, while only 3% of the Western labs used the method.

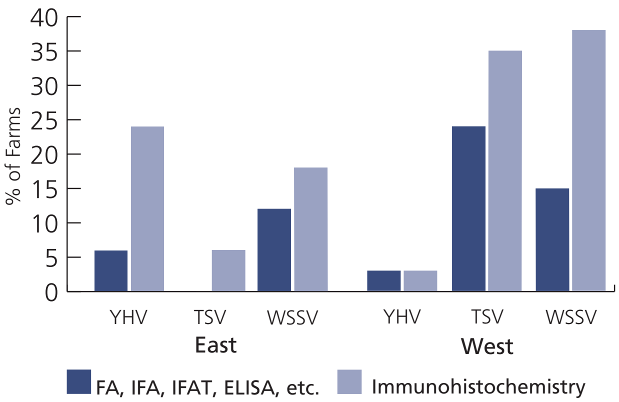


*Figure 4. Antibody-based tests performed. Immunohistochemistry was used more frequently than FA, IFA, IFAT, and ELISA in both hemispheres.*

Molecular methods such as dot blots, in situ hybridization assays with gene probes, and PCR/RT-PCR were the diagnostic methods used most frequently by the survey respondents. Molecular methods are rapidly becoming the preferred method for the detection of pathogens because of their speed, specificity, and sensitivity. However, histology is also widely used, especially as a general diagnostic tool and for confirmation of uncertain diagnoses initially made with other methods.

In terms of molecular diagnostic reagents, DNA dot blots were used more extensively in the West (90%) than the East (50%). This was also true for in situ hybridization (West 97%, East 42%).

Gene probes in dot blot tests on membranes were used most frequently for WSSV, Infectious Hypodermal and Hematopoietic Necrosis Virus (IHHNV), Necrotizing Hepatopancreatitis (NHP), and Hepatopancreatic Parvo-like Virus (HPV), with more tests for HPV in the East and more for NHP in the West (Figure 5). Gene probes used for in situ hybridization with paraffin-embedded histological sections were most frequently used for WSSV, TSV, IHHNV, YHV, NHP, and HPV, with a greater percentage of in situ tests done in the West. The gene probes used for the above procedures were typically purchased as kits.

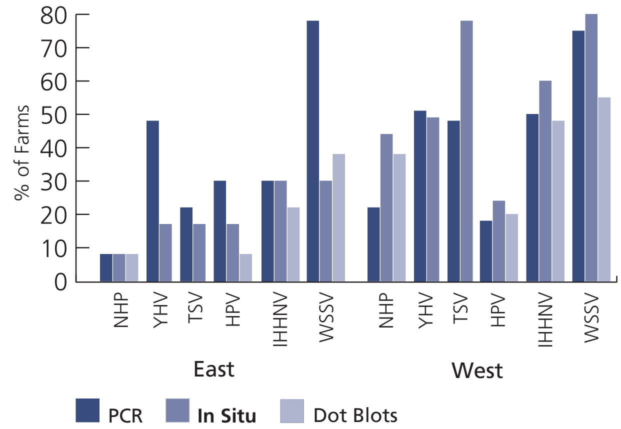


*Figure 5. Molecular methods used. More molecular tests were done in the West, while PCR and in situ hybridization were frequently used in both hemispheres.*

The majority of the respondents used gene amplification methods (PCR/RT-PCR), with similar capabilities in the East and West. Tests for WSSV and YHV were among the most often run tests in both hemispheres. Testing for TSV was more common in the West than the East, while testing for HPV was more common in the East. The use of commercial PCR kits was much higher in the West than the East.

About 90% of the laboratories indicated interest in participating in "ring tests," where a panel of unknown samples is submitted to participating laboratories for testing. Results would be returned to a central reference laboratory for evaluation and reporting of test results. Such tests may eventually lead to a better means of standardization and validation of test methods.

*The shrimp aquaculture industry relies heavily on molecular methods and, to a lesser extent, routine microbiology and histopathology.*

*Preparing fixed tissue for histopathology examination involves cutting and embedding in paraffin (above). Tissue blocks are then cut into ultrathin slices on the microtome for placement on microscope slides.*

## Summary

The development of disease diagnostic infrastructure in penaeid shrimp farming has lagged behind the growth of the industry. The production of farmed shrimp reached nearly 25% of the total world supply before there were many diagnostic laboratories and before diseases from WSSV and TSV were recognized as threats to continued industry growth and stability.

In the wake of the severe economic setbacks caused by the viral and bacterial disease pandemics of the 1990s, diagnostic infrastructure was rapidly developed in many of the shrimp-growing countries of the Eastern and Western Hemispheres.

The survey showed that the industry relies heavily on molecular methods and, to a lesser extent, the classic methods of routine microbiology and histopathology. In fact, the survey results indicated that more shrimp management decisions are likely to be based on PCR results for WSSV than on results for any other WSSV test or disease agent diagnosis. This trend toward reliance on DNA-based technologies in shrimp pathology came out of necessity because, unlike the livestock industry, which largely relies on serological and cell culture methods, development of these latter methods lagged well behind molecular methods.

While the shrimp industry can be proud of the diagnostic services provided by its numerous diagnostic laboratories, it must not become overconfident in the results provided by any single diagnostic method. No test is 100% accurate, even those viewed as "gold standard tests" for given diseases.

All diagnostic tests have limits of sensitivity and specificity. Many have seen postlarvae found "WSSV PCR negative" that later developed the disease in biosecure farms. Such false negative tests could be due to the limitations of sensitivity or failure of the sampling protocols to detect infected individuals in populations with a low prevalence of infection.

## Recommendations

This survey was conducted primarily to establish the status of shrimp disease diagnostic laboratories. However, the results of the study clearly supported the following recommendations:

- The application of modern molecular tests provides a powerful tool for the shrimp-farming industry, but these tests have limits. There is no substitute for patience in confirming the disease or health status of shrimp stocks before stocking them.
- Much can be gained by relying on more than one diagnostic method to increase confidence in shrimp health status, as well as confirming uncertain or significant diagnostic findings while building up a history of the health and disease status of particular shrimp stocks.
- Laboratories indicated an interest in ring tests as a method to verify quality control. This suggested that laboratories might be interested in accreditation programs – a good goal.

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# RESOURCE AUTHORITY

# *Estuarine Water Quality Monitoring*

GLOBAL AQUACULTURE ALLIANCE

# Estuarine Water Quality Monitoring

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## Principles

The number of shrimp farms and area under cultivation worldwide has expanded rapidly during the past 20 years. In many areas, shrimp farms have been developed in close proximity to one another along estuarine watercourses. These watercourses may have impaired exchange with the ocean, which limits their flushing with high-quality, oceanic water. Estuaries with restricted exchange are susceptible to water quality deterioration from inputs of point and nonpoint source pollution.

Awareness of estuarine water quality is important in shrimp farming because estuaries serve not only as sources of water for ponds, but often as destinations of farm effluents. In addition, estuaries serve as nursery areas for many species of fish and crustaceans.

Continued development and longevity of shrimp aquaculture rely on good source water quality. Overdevelopment of shrimp farms, either through intensification or increased pond acreage, along watercourses can deteriorate estuarine water quality to levels unacceptable for both shrimp farming and nursery grounds for aquatic animals.

*Estuaries serve as water and nutrient sources, as well as receivers of effluents from shrimp farms.*

Receiving water quality should be monitored continually to detect systematic degradation and assist in any needed regulation of pollution loading to watercourses. It is important to limit pollution loads to quantities that can be assimilated without causing serious water quality deterioration in coastal waters. Shrimp farmers and government resource authority personnel obtain data on estuarine water quality through systematically designed monitoring programs.

Estuarine water quality-monitoring programs track long-term changes in water quality variables along estuarine watercourses. These variables include nutrients such as nitrogen and phosphorus, biochemical parameters like chlorophyll a and biochemical oxygen demand, and microbiological variables such as *Salmonella* and *Vibrio*. The sources of nutrient enrichment for these watercourses include watershed runoff, industrial and urban effluents, and shrimp farm effluents.

*Water quality monitoring measures changes in nutrients and biochemistry in water sources.*

Unless every source of pollution to estuarine systems is quantified, the results of water quality-monitoring programs can only indicate overall water quality, and changes in water quality cannot be attributed to any one source. Because of the natural variability in estuaries, monitoring programs are ill suited to tracking short-term changes on the order of days to months.

Ideally, water quality-monitoring programs should operate one to two years before the construction of any shrimp farm in an area. Two years of data collection are preferred because of normal year-to-year variations. The data accumulated before shrimp aquaculture could then serve as a baseline to facilitate the identification of changes in water quality following the initiation of aquaculture activities. Logistical and economic challenges however, make such preaquaculture estuarine water quality programs difficult.

More common are monitoring programs that begin after shrimp aquaculture begins. After one or two years of continuous data collection, such programs provide baseline data for the current levels of shrimp pond area and management intensite. Future changes in water quality can be identified following additional shrimp farm development, substantial changes in pond management, or major changes in the sources or quantities of nutrient inputs into the systems. The only way to identify changes in estuarine water quality over the long term in an ever-changing environment is for the monitoring to continue indefinitely.

Estuarine water quality-monitoring programs can be operated by governments, producer associations, universities, or other groups. However, the most successful and credible programs are public-private partnerships that involve key stakeholders. Each group contributes financial, logistical, or intellectual support, and works collaboratively on all aspects of the program, from program development to management and proposed regulation.

*Whether done from boats or fixed stations on land, sampling must be conducted in a standardized process.*

## Survey

Estuarine water quality-monitoring programs worldwide were investigated through a 28-question component of the Global Shrimp OP Survey. Respondents were from Brazil, Ecuador, Honduras, India, Nicaragua, Thailand (two responses), and the United States (three responses). Complete data was provided on monitoring programs in Brazil, Ecuador, Honduras, Nicaragua, Thailand, and the USA.

Program implementation was varied (Figure 1). Collection of water samples for chemical and microbiological analysis ranged from weekly to quarterly (Table 1), and samples were analyzed for up to 15 chemical and five microbiological variables (Table 2).

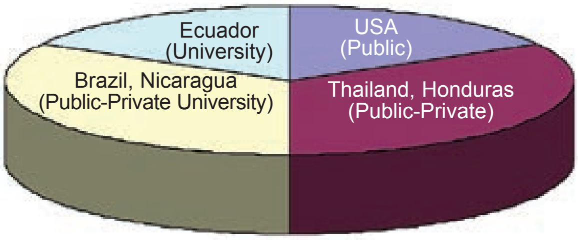



*Figure 1. Types of institutions that participated in the Estuarine Water Quality Monitoring survey.*

### BRAZIL

The estuarine water quality-monitoring program from Brazil involved government agencies, a producer association, universities, engineering/environmental firms, and local stakeholders. The majority of shrimp farms obtained their water from estuaries, but only 25% of the farms participated in the monitoring program.

Sampling stations were located near farm intakes and drains, with the distance between farm sampling stations typically over five kilometers. Samples were collected monthly at high and low tides, and analyzed with no microbiological analyses at a university laboratory for 13 variables. Determination of annual, seasonal, or longitudinal trends in water quality was impossible because of insufficient data.

### ECUADOR

A university implemented Ecuador's four-year-old monitoring program. Up to 25% of the country's shrimp farmers participated in this year-round program.

Source water for the majority of Ecuadorian farms came from estuaries, the Gulf of Guayaquil, or the Pacific Ocean. Proximity to shrimp farms, logistics, and circulation patterns in the open waters were the selection criteria for the fixed sampling station locations. Water samples were collected upstream from the last shrimp farm with upstream sample stations are as far upstream as navigable. One to two kilometers separated sampling stations.

Water samples were collected on a quarterly basis and analyzed at the university laboratory for nine chemical variables. No annual, seasonal, or longitudinal trends in data were reported because of insufficient data.

*Table 1. Reported frequency of water sample collection, tidal stage, and sample station location.*

| Variable | Brazil | Ecuador | Honduras | Nicaragua | Thailand | USA |
|---|---|---|---|---|---|---|
| Sample Frequency | Monthly | Quarterly | Weekly | Biweekly | Monthly | Monthly |
| Tide Stage | High and low | Varied | High | High and low | Varied | Low |
| Station Location | Farm inlet and outlet | Fixed | Farm inlet | Fixed | Outlet | Fixed |

*Table 2. Chemical and microbiological variables analyzed in collected water samples.*

| Variable | Brazil | Ecuador | Honduras | Nicaragua | Thailand | USA |
|---|---|---|---|---|---|---|
| **Chemical** | | | | | | |
| Total nitrogen | • | • | • | • | • | • |
| Ammonia-nitrogen | • | • | • | • | • | • |
| Nitrate-nitrite-nitrogen | • | • | • | • | • | • |
| Total phosphorus | • | • | • | • | | • |
| Soluble reactive phosphorus | • | | • | • | • | |
| Total alkalinity | • | | | • | | |
| Total hardness | • | | | • | | |
| Salinity | • | • | • | • | • | • |
| pH | • | | • | • | • | • |
| Total suspended solids | • | • | • | • | | • |
| Settleable solids | • | • | • | • | | • |
| Biochemical oxygen demand | • | | • | • | • | • |
| Chlorophyll *a* | • | • | • | • | | • |
| Oil and grease | • | | • | | | |
| Reactive Silicate | • | | • | • | | |
| **Microbiological** | | | | | | |
| Total coliform bacteria | | | | • | | |
| Fecal coliform bacteria | | | | • | | |
| *Vibrio* sp. | | | | • | • | |
| *Vibrio cholerae* | | | | • | | |
| *Salmonella* | | | | • | | |
| Total Bacterial Count | | | | | • | |

*Measuring water quality in an estuary.*

## HONDURAS

The estuarine water quality-monitoring program in Honduras, a producer association-government-university collaborative effort, had been in operation since 1993. Farmers collected water samples weekly at high tide from

ies into farm supply canals. The sampling stations were determined by farmer participation, but in Honduras, the majority of shrimp farms are located on four estuaries in one geographic area. The most upstream sampling station was downstream from the last farm on the estuaries.

Water samples were analyzed at the producer association-government laboratory for 13 water quality variables. No microbiological analyses were performed.

No long-term trend was observed for any water quality variable. Concentrations of water quality variables did increase during the dry season and with distance upstream. The upstream increase was thought to be the result of municipal and agricultural pollution.

*Sampling in several countries indicated higher effluent concentrations during dry seasons.*

*This map shows sample stations for estuarine water quality-monitoring programs in yellow.*

## NICARAGUA

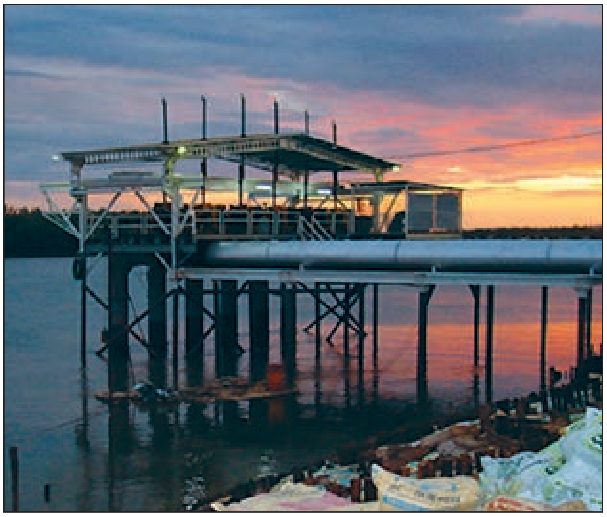
In Nicaragua, a water quality-monitoring program along the Estero Real entered its second full year at the time of the survey. This program was a collaborative university-producer association-government effort.

Water samples were collected at fixed sampling stations along the Estero Real every two weeks at high tide. The sampling station sites, selected based upon salinity intrusion and zones of low dissolved oxygen, extended upstream beyond the last shrimp farm. Water samples were analyzed at the university laboratory for 14 water quality and five microbiological variables.

The program had not been in progress long enough to allow comments on long-term trends in estuarine water quality. However, water quality variable concentrations were higher during the dry season and with distance upstream. There was not enough data to comment on seasonal or longitudinal trends for microbiological variables.

## THAILAND

In Thailand, the year-round estuarine-monitoring program involved the Thai Department of Fisheries and shrimp farmers, who collected and transported samples to the laboratory. Up to 25% of shrimp farmers participated in the program.



*Shrimp farms tended to be clustered around the estuaries from which they drew water.*

Source water for the majority of shrimp farms came from estuaries. Water samples were collected monthly at varied tide stages and often in the vicinity of farm drains. The distance between sampling stations was three to five kilometers.

Water samples were analyzed at a government laboratory for nine water quality and two microbiological variables. No annual, seasonal, or longitudinal trends in water quality or microbiological variables had been observed.

### UNITED STATES

A state agency was responsible for the estuarine water quality-monitoring program in the state of Florida, USA. This year-round sampling program, which had no shrimp farmer or producer association participation, had operated since 1980.

The majority of shrimp farms drew water from inland sources. Water samples were collected monthly from fixed sampling stations spaced more than five kilometers apart. Sampling station location was based on salinity intrusion, zones of low dissolved oxygen, and nitrogen and phosphorus concentrations.

Water samples were analyzed for nine water quality variables at government, university, or commercial laboratories. No microbiological variable was analyzed.

No annual trend was reported for any water quality variable because of insufficient data. However, water quality variable concentrations were reported to increase during the rainy season and with distance upstream.

*Water quality probes can be attached to long cables for monitoring parameters at depth in estuaries.*

## Summary

The Global Shrimp OP Survey revealed only six estuarine water quality-monitoring programs worldwide. Of these, five were located in the Western Hemisphere. These programs varied in scope, magnitude, and longevity, and provided program participants with water quality information that could be used in shrimp farm siting, development, and management decisions.

There is great opportunity to establish water quality monitoring in other shrimp-producing countries, especially in the Eastern Hemisphere, where the majority of the world's shrimp are produced. Producer associations; governmental resource management agencies; public, private, and regional universities; and other stakeholders are encouraged to initiate water quality-monitoring programs in water bodies associated with shrimp aquaculture.

The data generated from estuarine water quality-monitoring programs contributes to sound decisions regarding resource utilization and the sustainable development of shrimp aquaculture.

*Cooperation across regions and stakeholders is required for effective estuarine water quality monitoring.*

## Recommendations

This survey revealed that relatively little effort has been devoted to monitoring the effects of shrimp farming on coastal water quality. This is unfortunate, because such data is valuable to both shrimp farmers and organizations and agencies interested in protecting the coastal environment.

It is recommended that shrimp-farming associations in all nations attempt to work with government agencies, nongovernmental organizations, and international donor agencies to develop water quality-monitoring programs. These programs should be designed to reveal changes in coastal water quality over time, but also strive to partition pollutant loads among the different activities involved so the influences of shrimp farming can be quantified.

In addition, there should be continued effort to encourage shrimp farmers to reduce farm effluent volume and improve effluent quality. Water quality monitoring allows assessment of the benefits of the best practices promoted by Global Aquaculture Alliance and other groups.

The desirability of alliances among all stakeholders in the design and execution of water quality-monitoring programs cannot be overemphasized. Obtaining wide participation results in a sharing of the financial burden, a program design that accounts for the various interests of the stakeholders, and greater interest in the outcome of the effort.

Another important point about water quality monitoring is that the data is compared among sampling stations and over time. Thus, it is critical to rely upon reliable methods that are not changed frequently. Also, quality control procedures should be established in the laboratory to assure that data taken at different times can be compared in a meaningful way.

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# RESOURCE AUTHORITY

## *Estuarine Carrying Capacity*

GLOBAL AQUACULTURE ALLIANCE

# Estuarine Carrying Capacity

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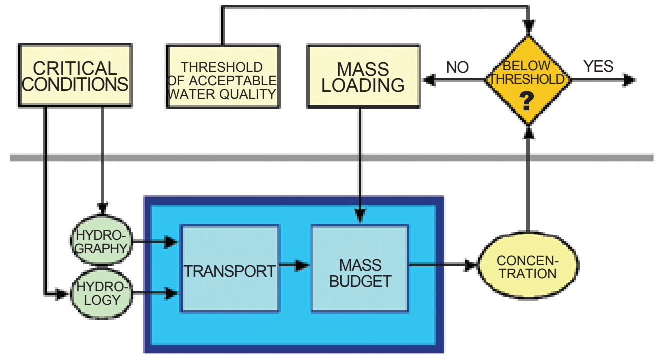
## Principles

Shrimp mariculture farms situated on estuaries take advantage of the large, vigorously mixed watercourses as receiving water for effluents that drain from the farm ponds. The carrying capacity of an estuary is the extent of shrimp farming that can be sustained on that estuary without degrading its water quality below an acceptable threshold determined by the requirements of the estuarine biota. If the estuary waters also serve as a source for pond influent water, the threshold can be established by the water quality requirements of the pond animals. The general procedure for establishing carrying capacity is shown in Figure 1.

Water quality is quantified by the concentrations of waterborne constituents. The most common parameters of concern are dissolved oxygen, total suspended solids (TSS), nutrients such as nitrogen and phosphorus, and toxic components of the pond effluent. For each parameter, threshold values must quantify acceptable water quality. For contaminants, the threshold is a maximum acceptable concentration. For an essential constituent like dissolved oxygen, the threshold is a minimum acceptable value.

Next, a set of conditions is selected for which the carrying capacity is to be established. Usually, these are the "critical" conditions under which water quality is maximally stressed, thereby assuring that under less-stringent conditions, water quality will exceed the threshold values.

MANAGEMENT DETERMINATIONS

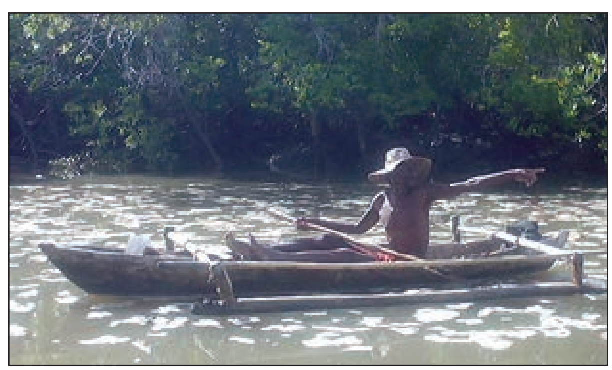



ANALYSIS AND MODELING

*Figure 1. General procedure for determining carrying capacity.*

The specifications of critical conditions and water quality thresholds are categorized as management determinations in Figure 1. In addition, a predictive model is used. This is a computational device capable of calculating the concentration in the estuary given the set of critical conditions and mass load from pond effluents.

The mass load that results in estuary concentrations exactly at the threshold values is the carrying capacity for that set of critical conditions, and is found by operating the model for a range of loads. This mass load of effluent must then be translated into more convenient measures of farm operation, such as pond area, stocking density, or feeding strategy.



*Local fishermen depend upon estuaries for a livelihood.*

### ESTUARIES

An estuary is conventionally defined as a semienclosed coastal water body with a free connection to the sea in which river water and sea water mix. Estuaries come in five broad classes: channel estuaries, drowned river valleys, fjords, lagoons, and tectonobays. Except fjords, all occur in the tropics and subtropics, and are used as a setting for shrimp aquaculture.

A common attribute of all estuaries is the complex character of their circulation. This arises from the complicated morphology of estuaries and the variety of hydrodynamic forces to which they are subjected, including tides, variable river inflows, wind stresses, density stratification due to salinity intrusion from the sea, and density currents (a consequence of the seaward gradient in salinity).

To address the carrying capacity of an estuary, two indispensable elements are required. First is an extensive set of field data that characterizes estuary transport and water quality. Second is a model capable of predicting the distribution of the key water quality parameters in the estuary, including the impacts of farm effluents.

*Determination of carrying capacity requires both accurate field data and practical modeling.*

Field data includes bathymetric and physiographic measurements, meteorological observations (especially rainfall), and stream flow information. These may be available from other agencies.

Physiography can be inferred from good maps, especially navigation charts that contain depth data in the navigable areas. Otherwise, a survey of systematic soundings and/or depth cross sections is necessary to set up the model.

Climatological data may not be available in remote regions, but observations of rainfall, cloud cover, and wind can be made at the farm site with little effort and expense. Of more importance are profiles of salinity, temperature, and dissolved oxygen taken at stations distributed throughout the estuary, especially in the vicinity of farm intakes and effluent drains. Multiprobe meters are suitable for profiling ranges typical of estuarine environments.

The most important quality of estuary data for carrying capacity determination is a long period of record. As noted above, estuaries are highly variable environments, and the data collection must quantify this range of variation. Routine monitoring should be maintained over several years to represent the spectrum of hydrometeorological conditions. Monthly intervals may suffice, but weekly would be far better.

Installation of an automatic water level gauge to monitor tide variation is strongly recommended. Automated salinity/temperature/dissolved-oxygen meters have come into routine use in recent years and proved to be useful supplements to routine hydrographic monitoring.

Automated monitoring is valuable because of the time continuity it affords. However, it is impractical to deploy automatic instruments throughout an estuary. Routine boat surveys remain the only acceptable means of collecting data with the necessary spatial continuity. Water samples should also occasionally be drawn for analysis of nutrients, TSS, biochemical oxygen demand (BOD), and other variables of concern.

## WATER QUALITY MODELS

Water quality models can be broadly classified as statistical (or empirical) and deterministic (or mechanistic). The former employs some functional fit of measurements, and the latter reflects the solution to a mechanistic equation.

These are theoretical extremes. All practical water quality models are, in fact, a combination of statistical and deterministic models. As a general rule, the more deterministic the model, the better its capability for handling "predictive" problems in which one or more elements of the environment are changed.

Determining the carrying capacity of an estuary is a predictive problem. Therefore, a deterministic model is generally necessary.

The mechanistic equations upon which water quality models are based include the mass budget (conservation of mass or mass-balance equation) for each water quality constituent of concern. The mass budget equation includes terms that represent the movement of the constituent and the kinetic processes that operate upon it in the watercourse.

Because the movement of water in an estuary is complex, a separate transport model is usually necessary, based upon the hydrodynamic equations. This "feed-forward" character of estuary models is indicated in Figure 1.

Table 1 is an example of a one-dimensional system. This is probably the simplest mathematical model applicable to the complex estuarine environment. It would be appropriate for a channel-type estuary or single arm of a drowned river valley estuary, provided that the modeling of cross section mean values of constituents is sufficient to address the water quality concerns.

momentum: $$\frac{\partial Q}{\partial t} + \frac{\partial uQ}{\partial x} = -gA\frac{\partial h}{\partial x} - gD\frac{Q^2}{C^2} \qquad (1)$$

continuity: $$\frac{\partial Q}{\partial x} + B\frac{\partial h}{\partial t} = q \qquad (2)$$

conservation of mass: $$\frac{\partial c}{\partial t} = \frac{1}{A}\left[-\frac{\partial (Qc)}{\partial x} + \frac{\partial}{\partial x}\left(EA\frac{\partial c}{\partial x}\right)\right] + \sum S_i \qquad (3)$$

$t$ = time
$x$ = distance along longitudinal axis
$Q = uA$ = longitudinal flow
$u$ = longitudinal velocity
$g$ = acceleration of gravity
$D$ = water depth
$h$ = water surface elevation
$C$ = Chezy friction coefficient
$A$ = cross section area
$B$ = surface width
$q$ = lateral inflow per unit length along channel
$c$ = section-mean mass concentration of substance
$E$ = longitudinal dispersion coefficient
$S_i$ = source or sink of substance (including kinetics and loads)

*Table 1. Mathematical formulas for a mechanistic model of a one-dimensional estuary.*

Even from this simplified perspective, the resultant equations are multivariate partial differential equations that cannot be solved analytically, but must be integrated numerically. Computer programs that integrate these and more complex equations have become widely available, but are not simple to set up and operate. They demand considerable skill on the part of the modeler, both with mathematics and knowledge of estuaries.

Analysis of field data provides the basic foundation for understanding an estuary. This understanding assists the selection and development of an appropriate model.

The data set provides essential inputs to the model, such as physiography and bathymetry. Field data also is necessary to establish values for such parameters as dispersion coefficients and reaction rates. These are the "statistical" elements incorporated into mechanistic models.

*Mathematical models provide an estimation of the complex processes affected by shrimp farming within estuary systems.*

Although models are complex mathematical devices, they are far simpler than the estuary systems they depict, so some assurance that the models in fact depict the real systems with adequate accuracy is needed. This is addressed through the process of model validation, a systematic comparison of model predictions to measurements in which all the controlling factors in the real world are represented as inputs to the model, and the accuracy of the resulting model prediction is quantified by direct comparison to field measurements.

# Survey

Despite widespread concern about source water quality and limits to farm development, the Estuarine Carrying Capacity section of the Global Shrimp OP Survey revealed practically no water quality-modeling activities around the world. Certainly one reason for this is the technical, highly specialized nature of estuary hydrographic analysis and modeling. However, an additional, perhaps dominating reason is the lack of familiarity with estuary modeling as a tool for farm management. Therefore, it is useful to briefly describe one application of modeling to determine carrying capacity.

## MODELING APPLICATION

This example examines the secondary estuaries of the Gulf of Fonseca, a large estuarine bay on the Pacific coast of Central America which has become the focus of the shrimp aquaculture industry in Honduras. The majority of shrimp farms are situated on the eastern arm of Fonseca, a deltaic region of low-relief salt flats fringed by mangrove swamps and an excellent setting for the construction of shrimp ponds (Figure 2).

The intakes and drains of the ponds are located on two main distributary networks: El Pedregal with its primary tributary La Jagua (including the flow of Rio Choluteca from Honduras), and the San Bernardo. Each of these distributaries is a channel estuary.

With a range that varies two to four meters, the large-amplitude semidiurnal tide in the Gulf of Fonseca is affected by both lunar phase and declination. A three-day record of tidal variation at the mouth of El Pedregal is shown in Figure 3. This range is typical of tidal variation a considerable distance up each of these estuaries. This is because the extensive tidal shelves in the fringing mangrove swamps provide a large tidal capacity that accommodates the tidal prism, as determined by a time-varying hydraulic model based upon equation 1 of Table 1.

Like many tropical regions subject to the annual migration of the Intertropical Convergence Zone, the Gulf of Fonseca region has distinct rainy and dry seasons each year. During the dry season, especially, dissolved oxygen problems have been experienced in the channel estuaries.

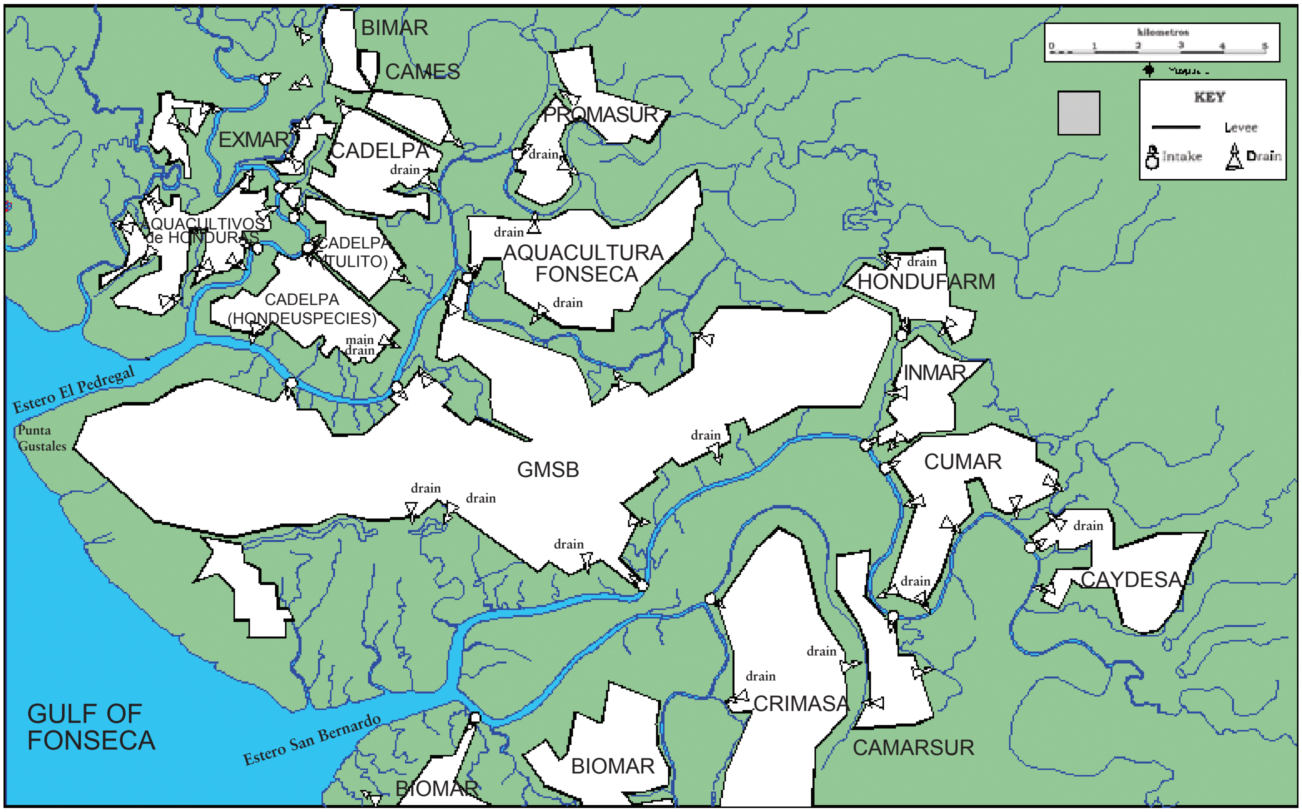



*Figure 2. Shrimp farms on the eastern arm of the Gulf of Fonseca.*

The longitudinal variation in water quality was modeled using equation 3 of Table 1 for both hydrological conditions. The vigorous tidal variation moves water up and down the length of the estuary, so the variation of any constituent that has a longitudinal gradient – salinity for example – will exhibit a prominent tidal component. Because large-scale, long-term variations in water quality are of primary interest in establishing carrying capacity, the complicating tidal variation was suppressed by modeling the tidal average concentrations.

The form of equation 3 is the same, except that the variables represent tidal means, and the dispersion coefficient must be increased to depict tidal mixing. An example of the model prediction and field measurements of salinity in the San Bernardo is shown in Figure 3. The field data in 2000 was taken at both high and low tides, from which the average salinity can be computed and the tidal excursion estimated by tracking the movement of a selected isohaline.

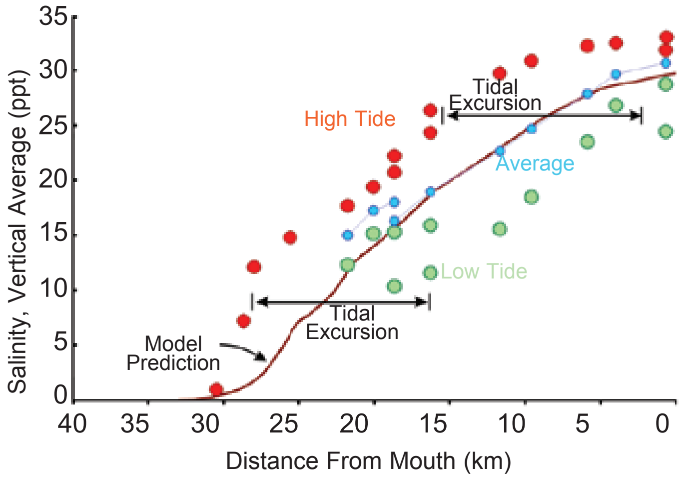



*Figure 3. Measured and modeled salinity in San Bernardo estuary in June 2000.*

The organic oxygen-depleting loads resulting from farm pond drainage were quantified by their BODs. Extensive incubations were performed on water samples from selected farms and estuaries to determine BOD and characterize the time progression of oxygen depletion, from which rate constants were determined.

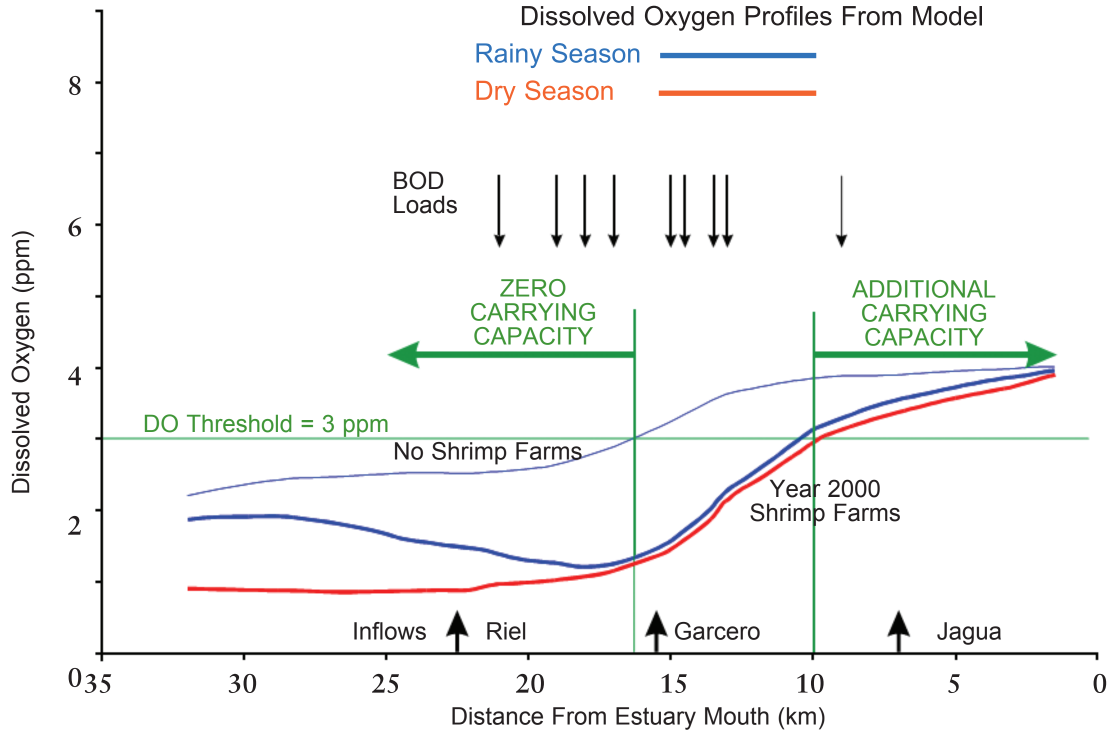



*Figure 4. Modeled profiles of dissolved oxygen in El Pedregal main channel.*

Data was compiled from the shrimp farms on pond areas, sources of influent, principal drainages, and daily exchange rates, all of which were used to specify the locations and magnitudes of the BOD loads. In addition, the natural BOD loads from watershed and tidal shelf exchanges were estimated based upon water samples from the estuaries.

Coupled models of BOD and dissolved oxygen (D.O.) concentration were then developed based on the numerical solution of equation 3 of Table 1, with sources and sinks appropriate for each. The models were satisfactorily validated against field measurements for a range of hydrometeorological conditions.

As an application example of the BOD/D.O. model in determining carrying capacity, consider the main channel of El Pedregal. The first step is to identify the critical conditions under which carrying capacity is established.

The watershed for this channel estuary is entirely confined to the coastal zone. Even in the rainy season, the inflow is modest. The dry season is clearly critical, in terms of water-quality stress.

If use of the estuary by both biota and shrimp farming were constant year-round, these would be the conditions for which carrying capacity would be determined. However, a number of migratory estuarine species appear in the estuary only during the rainy season. Moreover, there is the possibility of seasonal operation of the shrimp farms. Therefore, carrying capacity is needed for the rainy season, as well.

The next step in the carrying capacity procedure is selection of a threshold value for dissolved oxygen. It would be desirable to have site-specific information about the D.O. requirements of the indigenous species, but in lieu of this, a value of 3 mg/l (representative of the requirements of fish and other desirable aerobic organisms) is used.

The model results for the extent and operation of shrimp farms based upon data from the year 2000 are shown in Figure 4.

The primary drain locations defined the locations of the loads due to farm operations. Under both rainy and dry conditions, the D.O. in the upper reaches of the estuary was below threshold. The organic loads from the shrimp farms contributed to this condition, but were not solely responsible, as demonstrated by model runs with all shrimp farms removed.

The magnitude of the impact of farm organic loads on dissolved oxygen in the estuary can be judged by comparing the “No Shrimp Farms” and “Year 2000 Shrimp Farms” model profiles. Upstream from a point about 17 kilometers from the mouth of the estuary, the “no farm” D.O. fell below threshold due to the natural organic loads from inundation and drainage of the mangrove fringe and the reduced aeration rates in the narrow, sheltered tributaries.

Insofar as shrimp-farm operation is concerned, this upstream reach of the estuary had zero carrying capacity. Any additional load from pond drainage would drive the D.O. even further below threshold, as demonstrated in Figure 4. In contrast, the lower 10 kilometers of the estuary was above D.O. threshold even for the year-2000 operations, indicating there was additional carrying capacity for shrimp farming.

*Determining carrying capacity is not an exact science.*

In the intermediate 10- to 17-kilometer range, in which the majority of the farm drainage loads were injected, the carrying capacity was less than the 2000 shrimp farm level and depended on inflow.

Detailed model runs were carried out to identify the acceptable shrimp farm loads. As expected, the dry season was most constraining, and, indeed, poor water quality had already forced some of the shrimp farmers to discontinue operations during the dry season.

The importance of the assigned threshold value for acceptable D.O. in the determination of carrying capacity should be especially noted. Lower values would accommodate additional farm drainage, especially during the rainy season, while a higher value would constrain the level of farm operation even more. Clearly, additional studies are needed to refine this D.O. threshold value.

### VARIED FACTORS

This application also demonstrated some important facts about carrying capacity and its significance for shrimp farming in an estuary setting. Carrying capacity is not a single number like the capacity of a gas tank or elevator, but depends upon external conditions and is a function of position in the estuary. The locations of the organic loads are as important as their magnitudes, so the assimilative capacity for a single shrimp farm depends on where that farm is located in the estuary.

In the upper reaches of an estuary, where tidal range is diminished and flushing by inflow is limited, carrying capacity can be exceeded by even a modest farm operation, or there is no ability to assimilate the organic load, as is the case in the upper reach of El Pedregal.

*Maps of farms and estuaries are valuable in determining carrying capacity.*

The impacts of organic loads from shrimp farms extend over a considerable distance both upstream and downstream from the points of discharge. This is a direct consequence of the transport processes in estuaries, including the tidal excursion and internal circulations that transport material in both directions in the systems.

The fact that discharge impacts extend so far, even upstream, can be counterintuitive to those with experience chiefly on riverine systems who often incorrectly discount the impacts in shrimp farm designs. In many instances, farm intakes are placed too close to points of drainage under the apparent belief that because the intakes are upstream, they will not be exposed to contaminated drainage water. In some such cases, the length of the upstream tidal excursion is underestimated.

The example presented here focused entirely upon carrying capacity dictated by maintenance of dissolved oxygen. Other parameters may be of equal or even greater importance in delineating carrying capacity. Among these are the levels of nitrogen and phosphorus in the estuary waters and their effects on nuisance algal blooms as well as pond influent quality. Models for these parameters can also be developed.

## Recommendations

Planning for future shrimp farm development in an estuary setting, as well as management of existing shrimp farm operations, can benefit from the application of modeling to determine shrimp farm impacts on water quality and compute associated carrying capacities. Although advances in modeling techniques and technology continue, approximate estimates of carrying capacity carried out using simplified models on personal computers suffice for many operational problems.

An absolute essential for undertaking model development is an adequate database. Field data is employed for model inputs, parameter evaluation, and validation. Analysis of field data is also a necessary preliminary to develop an understanding of the hydrographic and transport behaviors of estuaries. In fact, sufficient field data may allow impact analyses and carrying capacity determinations to be made employing strictly statistical relationships.

Field data is required for tides, inflows, salinity intrusion and extrusion, stratification, and D.O. distributions. The data may be needed to define nutrient conversions and kinetics, and sediment transport and deposition. Because of the extreme variability of estuary environments, field data is needed over a substantial period of time.

It is recommended that a program of field data collection be implemented as a part of mariculture farm design and planning, as well as farm management for existing facilities. Such data collection should begin as soon as feasible. Even if modeling is never required, the field data will provide a valuable resource that documents the health of the estuary and occurrences of critical water quality conditions.

At a minimum, field data collection should include routine parameter profiling at a network of stations distributed throughout the estuary environment, not just in the proximity of the farm, and sample collection for water chemistry analysis. If degraded water quality episodes occur and limit farm operations, more sophisticated data collection may be warranted. This could include bathymetric surveys, automatic tide recorders, automatic gauges, and more intensive water sampling.

*Water quality should be regularly monitored throughout estuarine systems, not just at farm outlets.*

Finally, it should be noted that in situations in which more than one shrimp farm is in operation, estuaries become shared resources whose optimal use requires shared management. Data collection, analysis, and modeling become necessary – but not sufficient – elements for the broader cooperative management of the estuaries that also involve the difficulties entailed in balancing individual profits against shared liabilities. Despite the well-known difficulties of such operations, an objective assessment of carrying capacity based on thorough field monitoring coupled with sound analysis can form the foundation for cooperative farm management and preservation of the estuary environment.

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