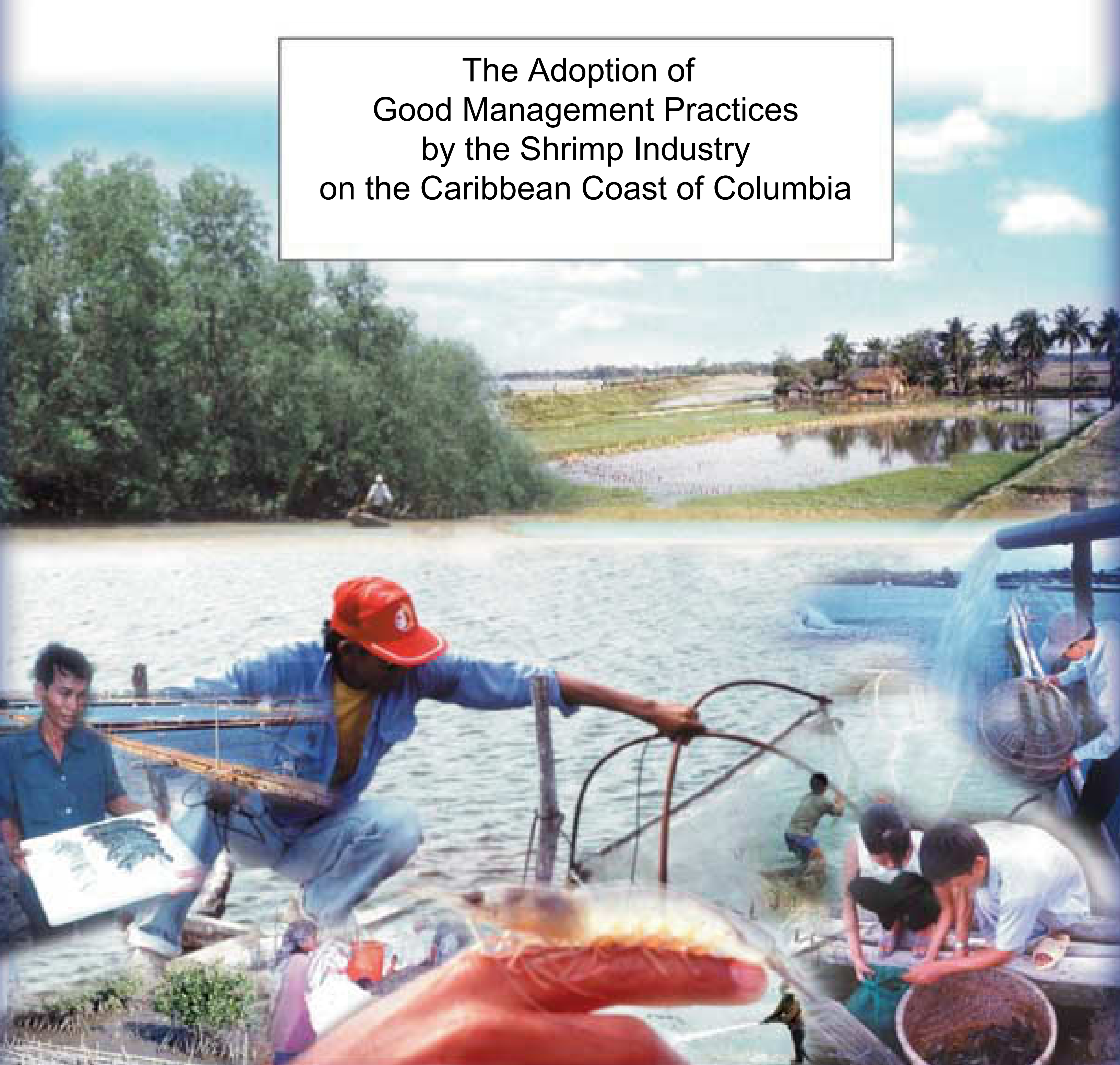
Shrimp Farming and the Environment



The Adoption of Good Management Practices by the Shrimp Industry on the Caribbean Coast of Columbia

A Consortium Program of:

THE ADOPTION OF GOOD MANAGEMENT PRACTICES BY THE SHRIMP INDUSTRY ON THE CARIBBEAN COAST OF COLOMBIA

Dominique Gautier

Department of Fisheries and Allied Aquacultures
Auburn University,
Alabama 36849 USA

A Report Prepared for the

World Bank, Network of Aquaculture Centres in Asia-Pacific,
World Wildlife Fund and Food and Agriculture Organization of the United Nations
Consortium Program on Shrimp Farming and the Environment

Preparation of this document

The research reported in this paper was prepared under the World Bank/NACA/WWF/FAO Consortium Program on Shrimp Farming and the Environment. Due to the strong interest globally in shrimp farming and issues that have arisen from its development, the consortium program was initiated to analyze and share experiences on the better management of shrimp aquaculture in coastal areas. It is based on the recommendations of the FAO Bangkok Technical Consultation on Policies for Sustainable Shrimp Culture[1], a World Bank review on Shrimp Farming and the Environment[2], and an April 1999 meeting on shrimp management practices hosted by NACA and WWF in Bangkok, Thailand. The objectives of the consortium program are: (a) Generate a better understanding of key issues involved in sustainable shrimp aquaculture; (b) Encourage a debate and discussion around these issues that leads to consensus among stakeholders regarding key issues; (c) Identify better management strategies for sustainable shrimp aquaculture; (d) Evaluate the cost for adoption of such strategies as well as other potential barriers to their adoption; (e) Create a framework to review and evaluate successes and failures in sustainable shrimp aquaculture which can inform policy debate on management strategies for sustainable shrimp aquaculture; and (f) Identify future development activities and assistance required for the implementation of better management strategies that would support the development of a more sustainable shrimp culture industry. This paper represents one of the case studies from the Consortium Program.

The program was initiated in August 1999 and comprises complementary case studies on different aspects of shrimp aquaculture. The case studies provide wide geographical coverage of major shrimp producing countries in Asia and Latin America, as well as Africa, and studies and reviews of a global nature. The subject matter is broad, from farm level management practice, poverty issues, integration of shrimp aquaculture into coastal area management, shrimp health management and policy and legal issues. The case studies together provide an unique and important insight into the global status of shrimp aquaculture and management practices. The reports from the Consortium Program are available as web versions (http://www.enaca.org/shrimp) or in a limited number of hard copies.

The funding for the Consortium Program is provided by the World Bank-Netherlands Partnership Program, World Wildlife Fund (WWF), the Network of Aquaculture Centres in Asia-Pacific (NACA) and Food and Agriculture Organization of the United Nations (FAO). The financial assistance of the Netherlands Government, MacArthur and AVINA Foundations in supporting the work are also gratefully acknowledged.

Correspondence: Dominique Gautier, E-mail: dgautier@granjasmarinas.hn

Reference:
Gautier D. 2002.“ The Adoption of Good Management Practices by the Shrimp Industry on the Caribbean Coast of Colombia ”. Report prepared under the World Bank, NACA, WWF and FAO Consortium Program on Shrimp Farming and the Environment. Work in Progress for Public Discussion. Published by the Consortium. 62 pages.

---

[1] FAO. 1998. Report of the Bangkok FAO Technical Consultation on Policies for Sustainable Shrimp Culture. Bangkok, Thailand, 8-11 December 1997. FAO Fisheries Report No. 572. Rome. 31 p.

[2] World Bank. 1998. Report on Shrimp Farming and the Environment – Can Shrimp Farming be Undertaken Sustainability? A Discussion Paper designed to assist in the development of Sustainable Shrimp Aquaculture. World Bank. Draft.

Abstract

This report discusses the recent history of shrimp aquaculture along the Caribbean coast of Colombia, with a focus on effective management practices that have been implemented since the mid-1990s. While the primary reason for using different practices has been preventing outbreaks of shrimp diseases, many such practices provide environmental benefits as well. Examples include reducing the use of water (and other resources) as well as ensuring that effluent entering natural water bodies is at least as clean as the intake water.

Strong growth prevailed in Colombian shrimp production from the early 1980s to 1993, when Taura Syndrome hit the industry and spread throughout coastal shrimp farms. Many farms closed, some of these never reopened; other farms have bounced back, and total production has been growing again since 1997. Since the Taura outbreak, research efforts led by the nation's industry association, Acuanal, have produced an ample domestic supply of broodstock and seedstock from animals selected for growth rates and resistance to disease. In addition to avoiding importation of shrimp and other marine animals that could carry disease, other elements of a biosecurity plan were implemented, including systematic disinfection of equipment, thorough testing, and certification that any animals to be moved from a facility are free of the viruses that cause White Spot Syndrome and Taura Syndrome, as well as the pathogens Baculovirus, Yellow-Head Virus (YHV), Infectious Hypodermal and Hematopoietic Necrosis Virus (IHHNV), and Necrotizing Hepatopancreatitis (NHP). Vibriosis occurs more commonly than any of the major diseases and is usually treated with antibiotics.

Biosecurity procedures are strict at hatcheries and nurseries, resulting in higher survival rates and healthier nauplii provided to the industry. The elements of ensuring biosecurity strive to prevent pathogen introduction or circulation, to diagnose quickly any disease that does appear and eliminate it, and to protect the genetic stock that is aquaculture's foundation. So far, these preventive actions have protected the industry on the Caribbean coast, but farms on the Pacific coast were hit with WSSV in 1999, and most in that area were closed in 2000. Fortunately, all shrimp-related facilities in the Caribbean coastal area that were closed from disease outbreaks have reopened and resumed their activities.

After surveying many facilities (seven shrimp hatcheries and nurseries, six companies that own and manage nine farms, and two processing plants), the author reports on common practices in place in 2000. These practices are contrasted with those used in 1997, when an earlier survey was conducted, and numerous inputs and outputs are compared between the two years. The six aquaculture companies operate farms that account for 88% of the area in production on the Caribbean coast, and the two processing companies process about 90% of that coast's total production. For each type of facility, the following topics are addressed: production methods, resource use, biosecurity measures, employment, efficiency, and economic aspects.

Shrimp farms in this area of Colombia have displaced undeveloped land or agricultural/ cattle farms that provided fewer jobs, rather than communities or communal resources. Destroying mangrove ecosystems has not been an issue for these farms; the small mangrove areas within farms have been preserved, as required by law. The farms as well as hatcheries, nurseries, and processing plants provide much-needed employment, and these jobs pay better and provide better benefits than the few other local options. Social services including schools, housing, and health care are often provided for local communities. Personnel turnover is very low. However, some workers, particularly those in processing plants, suffer from respiratory irritation and illnesses due to exposure to sodium metabisulfite, or skin irritation and infection from constant exposure to moisture.

The use of chlorine (increased since 1997) and sodium metabisulfite necessitates letting these residues dissipate in a tank or pond before discharging water, but not all farms have this equipment. Organic

fertilizer use has diminished, but fertilizers (including inorganic ones) still pose risks of contaminating shrimp ponds and eutrophying natural water bodies. Hazardous waste collection and treatment methods have been improved at shrimp farms. Water use in shrimp farms has decreased since 1997, lowering energy costs and reducing total production costs. New legislation that levies a tax based on measured differences between intake and discharge water now provides facilities, especially processing plants, with the incentive to further reduce costs by eliminating contaminants from effluent.

In 2000, the average survival rate at the shrimp farms surveyed was 65 percent, a notable increase over 1997. Many factors contribute to the higher survival rates, including lower stocking densities and greater use of chlorine, as well as the improved health of post-larvae and screening for disease mentioned above. The costs of nauplii and PL have both been substantially reduced. Stocking densities have decreased since 1997 by 35% on average. In sum, the higher yields and survival rates that stem from the selective breeding program have increased production and profits as well as supported other changes that improve environmental impacts.

Challenges that remain for the Colombian shrimp industry include implementing comprehensive environmental management systems; finding less expensive (and domestic) sources of shrimp food, especially for brooders; further improving the biosecurity of facilities (investing in costly recirculation equipment); and discovering and addressing the factors that reduce pond productivity during the dry months, so the whole year can be used for production. Environmental management should be further improved, perhaps by adopting a generally accepted certification program. Acuanal, the industry association, is central to providing training and information to producers as well as representing their interests in negotiations with government agencies.

Content

ABSTRACT IV

ABBREVIATIONS AND ACRONYMS VII

INTRODUCTION 1

MATERIALS AND METHODS 10

FINDINGS 11

- Hatcheries and Nurseries 11
- Grow-out Farms 21
- Resource Use and Feed Conversion Efficiency 29
- Processing Plants 39

DISCUSSION 44

- Introduction of Shrimp from Other Countries 44
- Health Management and Biosecurity 45
- Use of Drugs and Chemicals 47
- Production Efficiency 49
- Effluent Quality 50
- Zoning, Land Occupation, and Mangrove Protection 51
- Employment and Personnel Management 52
- Economic Aspects 53

CONCLUSIONS 54

ACKNOWLEDGMENTS 55

REFERENCES 57

Abbreviations and Acronyms

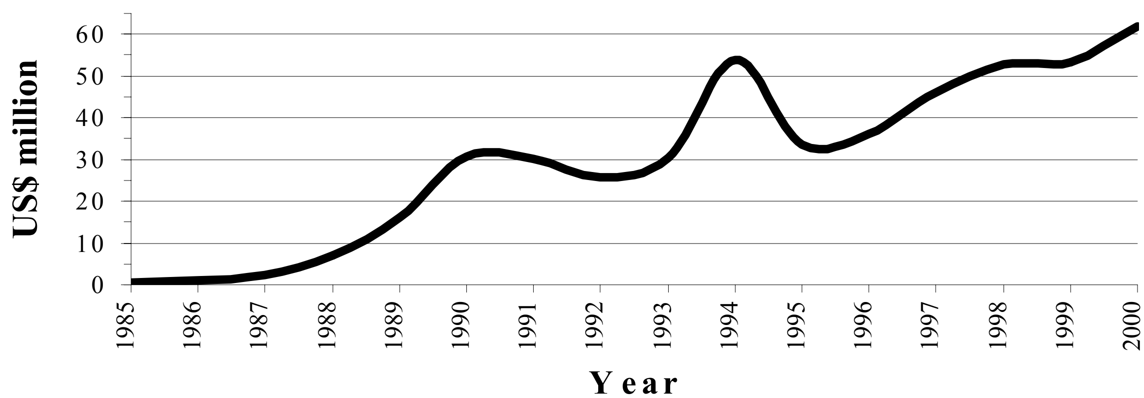
ARC	Autonomous Regional Coorporation
BMP	Best or Better Management Practices
BOD	Biological Oxygen Demand
$CaCO_3$	Calcitic (Agricultural Lime)
CERT	Tax Discount and Anticipated Tax Refunds
cm	Centimeter
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
EDTA	Disodium ethylenediamine tetraacetic acid
EIA	Environmental Impact Assessment
FAO	Food and Agriculture Organiziation of the United Nations
FCR	Feed Conversion Ratio
FDA	US Food and Drug Administration
g	Gram
ha	Hectare
HACCP	Hazard Analysis Critical Control Point
HCL	Hydrochloric acid
IHHNV	Infectious Hypodermal and Hematopoietic Necrosis Virus
INPA	National Institute of Fisheries and Aquaculture
INVIMA	Instituto Nacional de Vigilancia de Medicamentos y Alimentos
OIE	International Organization of Epizootics
ISO	International Standard Organization
l	Liter
m	Meter
m^2	Square meter
m^3	Cubic meter
mg	Milligram
MIC	Minimum inhibitory concentration
ml	Milliliter
MT	Metric Tons
NACA	Network of Aquaculture Centres in Asia-Pacific
NHP	Necrotizing Hepatopancreatitis
PCR	Polymerase chain reaction
PL	Post Larvae
PTO	Power Take Off
SO_2	Sulfur dioxide
TSS	Total Suspended Solids
TSV	Taura Syndrome Virus
WB	World Bank
WSSV	White Spot Syndrome Virus
WWF	World Wildlife Fund
YHV	Yellow Head Virus

Introduction

The production of shrimp (*Litopenaeus vannamei* and also *L. stylirostris* in the past) is the principal aquaculture activity in Colombia measured by export value, with an estimated US$62 million for 2000 (Figure 1). The total production of cultured shrimp has oscillated between 6,000 and 10,000 MT annually during the past 10 years, with pond area in use fluctuating around 3,000 ha (Figure 2). The production of tilapia (mostly red hybrid) is the main aquaculture activity in Colombia measured by total production, with about 14,000 MT produced in 1996 (INPA, 1997). In 1996, rainbow trout production was 4,500 MT and native freshwater fish production was 6,200 MT. Wild shrimp catch from both Pacific and Caribbean coasts was 5,055 MT in 1996, 90% of which was exported.

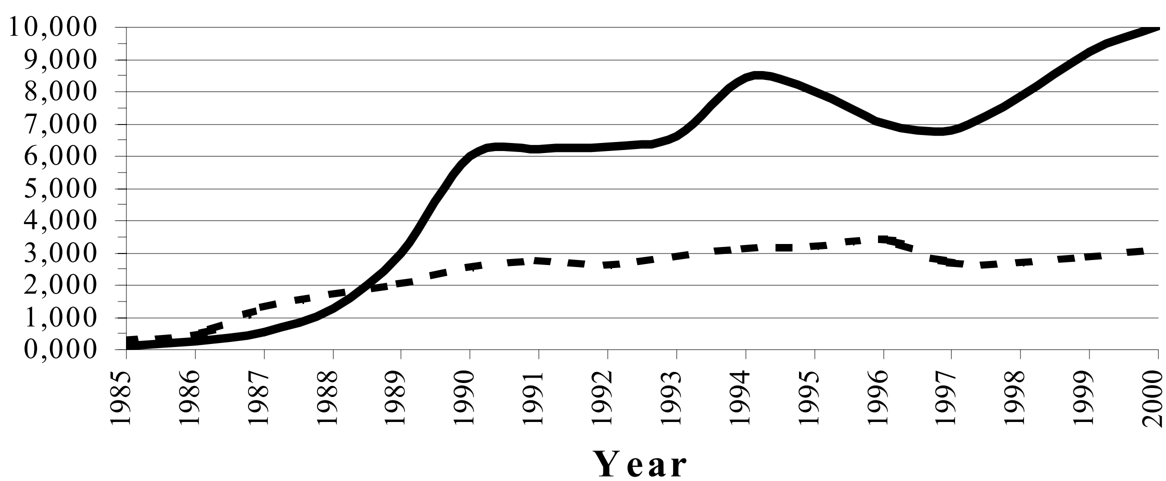
Shrimp aquaculture facilities (including hatcheries, nurseries, farms, and processing plants) are located on the Caribbean coast between the Magdalena and Sinu rivers; and on the Pacific coast, in Tumaco and the surrounding area near the Ecuadorian border (Figure 3).

Figure 1. Export value (in US$ millions) of farmed shrimp in Colombia, 1985–2000.



Source: ACUANAL. Value for 2000 is an estimate.

Figure 2. Changes in hectares in production (dotted line) and total production in MT (continuous line) of farmed shrimp in Colombia.



Source: ACUANAL. Values for 2000 are estimates.

The Colombian shrimp industry began in the early 1980s with the construction of the first hatcheries and farms. The Colombian government supported the development of shrimp farming financially. From 1985 on, the shrimp industry received subsidized loan interest rates, tax discounts and anticipated tax refund (CERT) equal to 20% of export sales. The value of the CERT has decreased regularly (2000 value is 4.25%) and will disappear in 2001. At that time, the shrimp industry will not receive any aid from the government in the form of subsidized loans or tax discounts and refunds. But the Colombian government still helps the shrimp industry through grants for research and development projects.

The Colombian government recognized the shrimp industry early on as a good opportunity for export development. Projections were made for 30,000 ha of ponds and an annual production of 25,000 MT and export value of US$135,000 million (Currie 1998). In contrast, the number of facilities has remained limited: 26 hatcheries and nurseries (Table 1), 29 farms (Tables 2a and 2b), 8 processing plants (Table 3); and the productive area slowly increased until the year 1996, up to only 3,436 ha (Figure 2). The early increases in production area came from the creation of new farms in the 1980s, but later increases resulted from the construction of additional ponds at existing farms in the 1990s. The discrepancy between expectations and real results can be explained by initial technical difficulties and financial weaknesses (Currie 1998).

Figure 3. General location of shrimp aquaculture facilities in Colombia (circles indicate main areas).

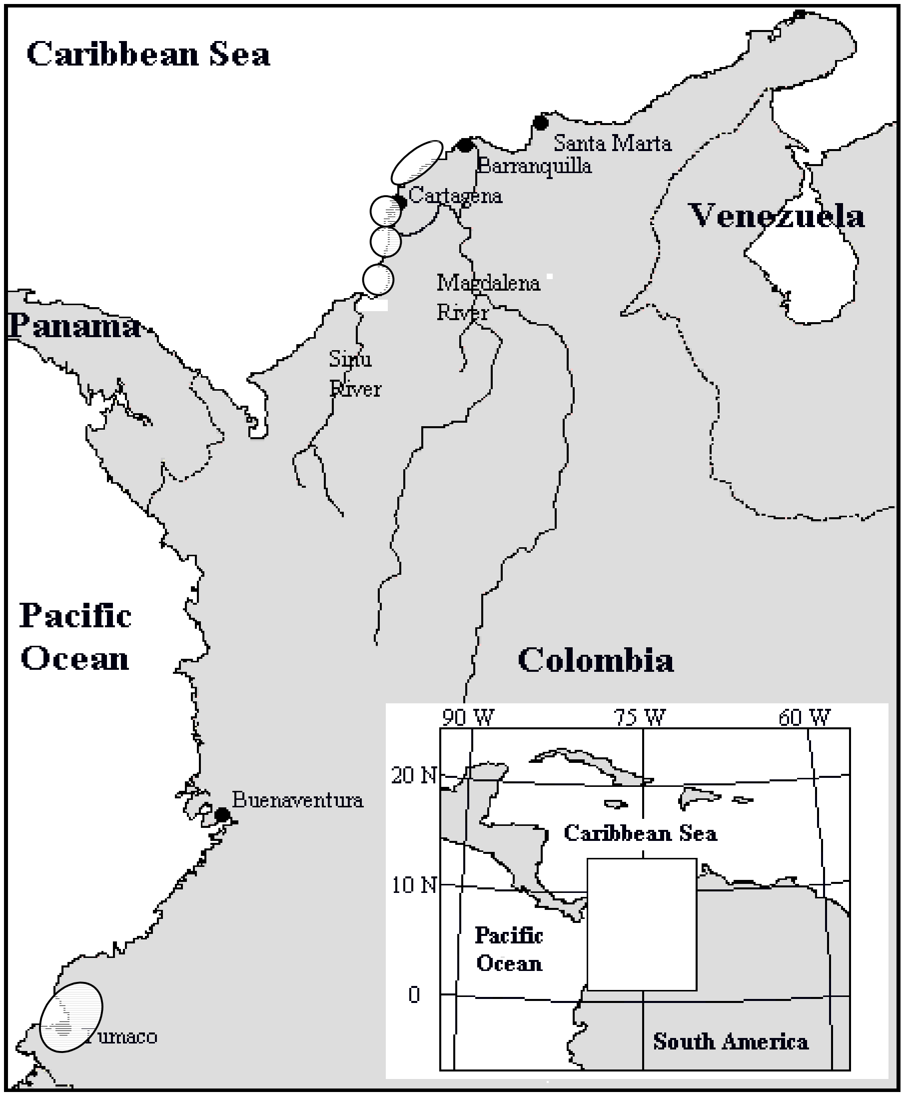


Table 1. Capacity of all shrimp hatcheries and nurseries ever built in Colombia. (Facilities are listed from north to south.)

Facility (company)	Company activities*		Location (Department)	Capacity		Comments
	This facility	Others		broodstock	nauplii (mil)	
Caribbean coast						
Inversiones Camaroneras	H/N		Ciénaga (Magdalena)	800	N/A	
Post-Larvas del Caribe	N	H/F	Pueblo Nuevo (Bolívar)		25	surveyed
Ceniacua (Acuanal)	H	A	Punta Canoa (Bolívar)	2000	N/A	surveyed
Kuruma	N		Punta Canoa (Bolívar)		10	closed
Productora de Larvas	N		Punta Canoa (Bolívar)		19	closed
Idelcaribe	H	N/F	Punta Canoa (Bolívar)	1200		surveyed
Hidrocultivos de la Costa	N		Arroyo de Piedra (Bolívar)		20	surveyed
Postlarvas Kalamary	N		La Boquilla (Bolívar)		13	
Acacias del Mar	N		La Boquilla (Bolívar)		12	
Rancho Chico	N		La Boquilla (Bolívar)		12	surveyed
Acuatec	N		Isla Barú (Bolívar)		19	surveyed
Islamar	H/N		Isla Barú (Bolívar)	3600	40	
Tigua (Cartagenera de Acuacultura)	H/N	F/P/FP	La Libertad (Sucre)	700	25	surveyed
Larvas de Tolú	N		Tolú (Sucre)		17	
Postlarmar	N		Tolú (Sucre)		40	
Agrocalao	H/N		Punta Bolívar (Córdoba)	800	16	
Veur	N	F	Punta Bello (Córdoba)		30	
Pacific coast						
Balboa/Ceniacua	H	F/A	Tumaco (Nariño)	N/A		
Idelpacífico	H/N	P	Tumaco (Nariño)	1400	35	
Larvacol	H/N		Tumaco (Nariño)	960	20	closed
Inbiomar	N				8	closed
Larvas de Tumaco	N				N/A	
Larvamar	N				N/A	
Piscifactoria El Diviso	N				N/A	
Post-Larvas del Pacífico	N	F			14	closed
Semaco	N				32	closed

N/A: not available. *H: hatchery; N: nursery; F: farm; P: processing plant; FP: feed plant, A: association.

Table 2a. Production area of all shrimp farms ever built on the Caribbean coast of Colombia (listed from north to south). Farms surveyed for this study are indicated.

Farm (Company)	Other Activities*	Location (Department)	Production Area (ha)		
			Operating Farms	Closed Farms	Farms Surveyed
Aquacultivos del Caribe	H/N	Pueblo Nuevo (Bolívar)	122		122
Agromarina Santa Ana		Canal del Dique (Bolívar)	90		90
AMC (C.I. Océanos)	P	Isla de Barú (Bolívar)	14.5		14.5
Barú Shrimp		Isla de Barú (Bolívar)	60		
Biomar		Isla de Barú (Bolívar)	10		
Agrovenezia		Isla de Barú (Bolívar)		24	
Colombiana de Acuacultura (C.I. Océanos)	P	Isla del Covado (Bolívar)	411.5		411.5
Camarones del Caribe (C.I. Océanos)	P	Isla del Covado (Bolívar)	229.5		229.5
Proacuicola		Isla del Covado (Bolívar)	160		160
Acuipesca		Isla del Covado (Bolívar)		220	
Cartagenera de Acuacultura	H/N/P/FP	La Barce (Sucre)	422		422
Agrotijó		San Antero (Córdoba)	70		
Camarones del Sinú (C.I. Océanos)	P	San Antero (Córdoba)	19		19
Agrosoledad	H/N	La Doctrina (Córdoba)	286		286
Agromarina Casamar	N	San Bernardo (Córdoba)	90		
Total, Caribbean coast			1984.5	244	1754.5

*H: hatchery; N: nursery; F: farm; P: processing plant; FP: feed plant, A: association.

Table 2b. Production area of all shrimp farms ever built on the Pacific coast of Colombia (listed from north to south).

Farm (Company)	Location (Department)	Production Area (ha)		
		Operating Farms	Closed Farms	Abandoned Farms
Produmar	Tumaco (Nariño)	104		
Mariscal	Tumaco (Nariño)			100
Pexco	Tumaco (Nariño)			75
Nautilus	Tumaco (Nariño)			20
América	Tumaco (Nariño)			20
Aquamar	Tumaco (Nariño)		204	
Amparito (Agromarina Tumaco)	Tumaco (Nariño)	24		
San Luis (Agromarina Tumaco)	Tumaco (Nariño)	92		
La Perla	Tumaco (Nariño)		136	
Maragricola	Tumaco (Nariño)		250	
Maja	Tumaco (Nariño)		95	
Compañia Camaronera Balboa	Tumaco (Nariño)	220		
Güinulero	Güinulero (Nariño)		138	
Caribeña	Candelillas del Mar (Nariño)			80
Total, Pacific coast		440	823	295

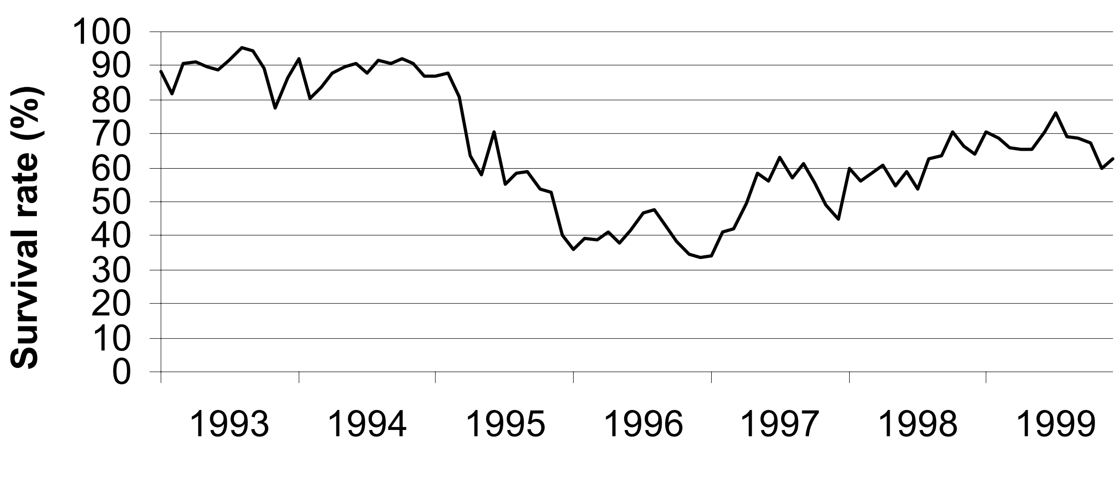
Table 3. Colombian plants that process cultured shrimp as well as wild shrimp and other marine products

Plant (Company)	Location (Department)	Capacity (tons/day)	Comments
Caribbean coast			
Coapesca	Cartagena (Bolívar)	N/A	
C.I. Antillana*	Cartagena (Bolívar)	N/A	
C.I. Océanos	Cartagena (Bolívar)	25	surveyed
Vikingos de Colombia*	Cartagena (Bolívar)	N/A	
Cartagena Shrimp Company	Cartagena (Bolívar)	16	surveyed
Pacific coast			
El Delfin Blanco*	Tumaco (Nariño)	N/A	
Idelpacífico	Tumaco (Nariño)	20	
Maragricola	Tumaco (Nariño)	16	closed

N/A: not available. *Companies specializing in fisheries products that process cultured shrimp as a minority of their products.

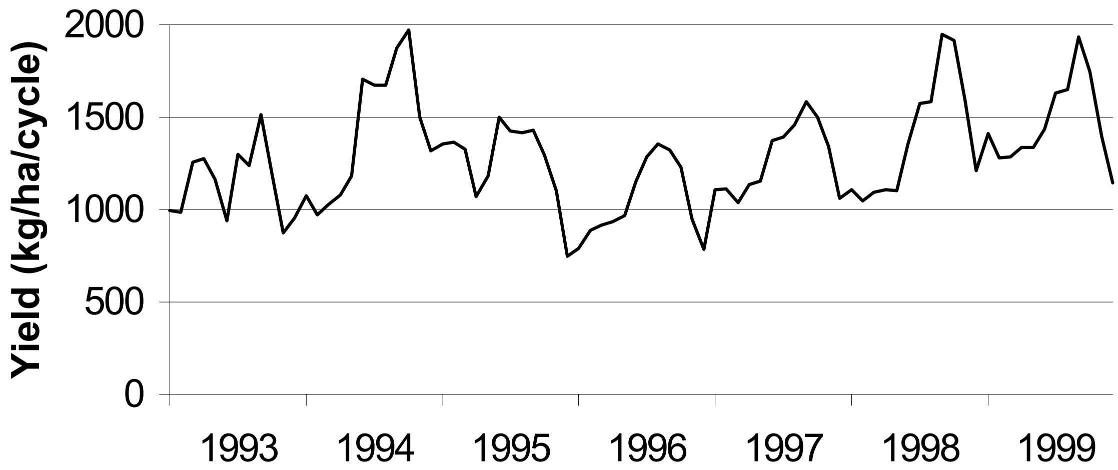
Colombian shrimp production from aquaculture reached 8,400 MT in 1994 and then declined due to high mortality rates caused by the Taura Syndrome, which appeared around the whole country. More recently, White Spot Disease has stricken farms in Tumaco. Taura Syndrome first appeared in Tumaco on the Pacific coast in 1993, and then spread to the Caribbean farms in 1994 and 1995 (Vallejo and Newmark 1996; Newmark et al. 1997). For example, in a farm located on the Caribbean coast, the survival rate was around 90% until 1994, and then decreased to below 40% in 1995 (Figure 4). From 1997, survival rates increased through the use of locally produced seedstock. Broodstock is selected from survivors from previous production cycles at the same farm. Survival rates now average 65%, but have not returned to 1994 levels (Figure 4). As a consequence of the low survival rate, the yield per production cycle also decreased in 1995 and 1996 from 1994 values (Figure 5). The farm's staff, however, learned to manage production in the presence of the Taura disease. Consequently, even with low survival rates, yields in 1997 and 1998 were as high as in 1993 and 1994, respectively (Figure 5). The recent history of disease and production at this farm is typical of farms on the Caribbean coast of Colombia.

Figure 4. Changes in survival rates at the farm Colombiana de Acuicultura.



Source: Remolina–C.I. Océanos.

Figure 5. Changes in yield per production cycle at the farm Colombiana de Acuicultura.



Source: Remolina–C.I. Océanos.

As a consequence of high mortality from 1994 in Tumaco and from 1995 at Caribbean farms, some companies ran out of money and facilities were closed. Some of them located on the Pacific coast were abandoned (Table 2b). But most of the farms that are closed at a given time cannot be considered abandoned. Some farm owners are big companies that have other ongoing activities. Sometimes, they decide to start the operation again. Other closed farms are on the market for sale or rent. New companies start operations again at farms that were once closed. Such changes are rather common since the Colombian industry was severely hit by Taura Syndrome, especially in Tumaco.

The industry progressively recovered, thanks to the development of a program for producing local broodstock (Suárez 1998; Suárez et al. 1999). National production levels rebounded to 8,086 tons in 1998, a record production of 9,227 tons was reported in 1999, and the 10,000-ton mark should be reached in 2000 (Figure 2). Some previously closed farms opened again, either managed by the same company or a new one. Unfortunately, in 1999, the farms located in Tumaco (Pacific coast) were hit by the White Spot Disease, which had devastating consequences for production in this region. Most farms located in the Tumaco area are now closed (Table 1b). For that reason, this study focused primarily on the facilities located on the Caribbean coast. By August 2000, White Spot Disease had not reached the farms located on the Caribbean coast. It is believed that the domestic program of broodstock production that made the Caribbean industry self-sufficient for seed supply allowed it to avoid the disease.

This report addresses health management issues and describe biosecurity procedures implemented by farmers. In addition to their capacity to avoid the introduction of new diseases, Colombian farms located on the Caribbean coast have the highest yield per hectare and per year in the Americas (Lucien-Brun 1997; Currie 1998), with around 4,000 kg/ha/year produced with semi-intensive strategies (no aeration). Only a few intensive farms equipped with aeration devices produce higher yields. This report analyzes in detail the management practices used in Colombian shrimp farms and quantifies the efficiency of resource use.

Several reports voicing concerns about the environmental sustainability of the shrimp industry have appeared internationally (Boyd and Clay 1998; Primavera 1998); such concerns have also been expressed by Colombian producers during the past few years. Colombian farmers feel that environmentalists' criticism of the shrimp industry in general does not apply to Colombia, especially regarding social issues or most environmental issues, such as mangrove destruction. Nevertheless, after a decade of constant improvement in production, Colombian farmers have identified environmental limitations to their progress. First among these, the general deterioration of water quality in coastal areas related to terrestrial runoff could be the main cause of growth problems and was also partially responsible for the Taura Syndrome outbreak. Colombian farmers also believed, some through direct experience, that the threat from tourism and urban development, and the contamination of coastal waters by industrial and agricultural activities, could endanger their activities.

On the other hand, the Colombian government created the Ministry of the Environment in 1993, which began to issue appropriate legislation for controlling the environmental impact of all activities, including aquaculture. Pressure from this environmental authority has mounted rapidly during the last few years, especially on mangrove protection and waste generation and management. Additionally, some big Colombian shrimp companies (exporters) grew concerned about increasing criticism from international NGOs and environmentalists of shrimp culture in general, including social and environmental issues (Primavera 1993, 1998; Boyd and Clay 1998).

In response to these concerns, Colombian shrimp producers decided to evaluate the environmental status of their industry in light of the new legislation and the problems pointed out by the international debate. A study was performed in 1997 by Echavarría et al. (1998) to analyze the environmental situation and to identify some priority actions for the shrimp industry to undertake. This survey of the main Colombian facilities identified some issues that should be addressed by the shrimp industry.

- The importation of post-larvae (mainly from Panama and Ecuador) and the introduction of exotic species (*Litopenaeus vannamei* and *L. stylirostris*) into the Caribbean coast may have introduced pathogens and could harm native wild stocks of other species. Although no negative impact of shrimp culture has been identified on natural shrimp stocks, the threat of new diseases in cultured shrimp was strong enough to conclude that preventing the introduction of foreign animals was an absolute priority.
- The use of chemicals (mainly chlorine, sodium bisulfite, and pesticides) and antibiotics in hatcheries, farms, and processing plants has generated some risks for both humans and the environment. Management procedures had to be developed to guarantee the proper use of hazardous products.
- The quality of hatchery, farm, and processing plant effluents was not documented, and a few observations raised the concern of possible contamination of receiving water bodies. Producers thus recommended that monitoring be undertaken to carefully assess the composition of effluents, and management practices and treatment methods be developed to improve effluent quality when necessary.
- The management of certain wastes that are potential pollutants (oils, inorganic solids, chemicals) generated in remote areas, particularly on farms, needed to be addressed.
- The possible impact of farm construction and operation on mangrove ecosystems, through waterlogging and discharge of effluents remained unknown and should be assessed.
- The possibility of having areas with high concentrations of farms in the future would require some zoning assessment and policy.
- Finally, since some companies ran out of money after the Taura Syndrome outbreak, the conversion of closed facilities needed to be addressed.

This report evaluates the level of adoption of better management practices or actions developed to address the issues mentioned above.

Materials and Methods

Three questionnaires were developed to survey hatcheries, nurseries, farms, and processing plants. Questionnaires were designed to identify and evaluate better management practices (BMPs) proposed by Boyd (1999a), and also to consider the issues identified by Echavarría et al. (1998), who surveyed the same companies in 1997. The survey was also designed to evaluate the environmental, economic, and social impacts of the industry.

Key companies for this research were selected because of their importance to the industry, based on volume of production and strategic position (leadership, research and development, history). Managers of the selected companies were interviewed in March 2000. Seven hatcheries and nurseries were surveyed. They represent approximately 43% and 36%, respectively, of the capacity of all hatcheries and nurseries along the Caribbean coast (Table 1). Six companies representing nine farms were surveyed. They operate 1,754 ha, which is 88% of the current total production area on the Caribbean coast (Table 2a). Two processing plants that process almost exclusively cultured shrimp were surveyed. They process approximately 90% of the Caribbean farms' production.

Weighted means and standard errors were calculated with Systat® for relevant parameters. Results were compared with data collected by Echavarría et al. (1998) to evaluate the evolution of the industry between 1997 and 2000. This report will analyze how extensively BMPs have been adopted, obstacles to and costs of adoption, and implications.

It is worth describing the organization of the Colombian shrimp industry, to provide a complete understanding of some actions undertaken collectively. As shown in Tables 1, 2, and 3, the Colombian shrimp industry has a limited number of companies, and leadership is concentrated in a few of them. Almost all shrimp companies are members of Acuanal (Asociación Nacional de los Acuicultores de Colombia), an association that interfaces between producers and the government and public institutions. Acuanal negotiates legislative measures in favor of the industry, collects funds, circulates information among the members, and is the centre of the negotiations and the decisions taken by producers all together. In 1993, Acuanal created a research center named Ceniacua (Centro de Investigación de la Acuicultura de Colombia). Ceniacua started research projects in 1995 on hatcheries and farms, and set up two research labs, in Cartagena and Tumaco. In 1996, Acuanal received a US$ 1.8 million government grant to develop local seedstock of *L. vannamei* from broodstock produced by Colombian farms. Acuanal acquired a hatchery near Cartagena and signed agreements in Tumaco to expand local hatcheries. The genetics-based program led by Ceniacua includes two levels. First, the best brooders are obtained from Colombian farms, and they are used to produce enough post-larvae to supply all Colombian farms, thus avoiding importation. The second level uses selection in order to improve the performance of the stock, in terms of, first, growth, and second, resistance to diseases. This second program is assisted by the Institute Akvaforsk (Norway), which specializes in aquaculture genetics.

Findings

Hatcheries and Nurseries

The first hatcheries and nurseries were built in the early 1980s. Today, nurseries are more numerous than hatcheries (Table 1). In the past, nurseries imported nauplii, mainly from Panama for facilities located on the Caribbean coast, and from Ecuador for facilities located in Tumaco. In both Ecuador and Panama, brooders were caught in the wild. By contrast, today all nauplii bought by nurseries located on the Caribbean coast are produced in the six local hatcheries (Table 1). All broodstock is also produced in farms located on the Caribbean coast of Colombia. Thirteen nurseries (Table 1) produce enough post-larvae (PL) to cover the demand of about 140 million per month. Since mid-1999, hatcheries and nurseries have produced even more PL than are needed in Colombia. They are exported to other Latin American countries through Aquagen, a new company owned by Colombian producers and partners. PL are very much in demand since the Caribbean coast of Colombia is, along with Belize, Venezuela, and Brazil, an area free of White Spot Virus—one of few such areas in the Americas.

Design and Construction

Facilities surveyed were built on small properties of at most a few hectares (Table 4). Most of them were built very close to the seashore, but above the high-tide mark. Sites with no or very little influence from rivers were chosen, in order to have very stable salinity (Table 4). No hatcheries or nurseries are located in the same sites as farms. All facilities are made of concrete and weather-resistant materials, and were built to last.

All facilities surveyed treat all the pumped-in water in some way before it is used. Most facilities are equipped with a sand filter, activated carbon, a tank for chlorinating, cartridge filters, or ultraviolet lamps, or some combination of these (Table 6). One facility is equipped with a protein skimmer and a biofilter to allow for the recirculation of water. Another facility also plans to recirculate water soon.

Table 4. Characteristics of the site's land, and water use, in hatcheries (H) and nurseries (N) surveyed.

Facility	**Activity**	**Area**	**Land type (%)**			**Salinity range**		**Pumping height**	**Water abstraction**	**Water exchange rate in tanks (%/day)**		
		(ha)	Highland	Mangrove	Beach	Min.	Max.	(m)	(m^3/day)	Brooders	Nauplii	PL
1	H	2.5	100							175		
2	H+N	4	100			31	37	4	1200	300	200	
3	H+N	N/A	100			35	40		500	100		100
4	N	0.5	100			35	36	7	200			100
5	N	2	75	25		27	30	4.5	180			100
6	N	0.3			100	32	35	8	60			50
7	N	1	100			32	36	13.5	300			N/A
Weighted mean			93.9	3.7	2.4	32.2	36.1	8.6	432.5			
Standard error			2.7	1.4	2.4	0.1	0.1	0.1	10.1			

N/A: not available

Table 5. Production of hatcheries (H) and nurseries (N) surveyed.

Facility	**Activity**	**Producing since:**	**Capacity (m^3)**	**Monthly production**		**Survival rate (%)**
				PL (million)	**Nauplii (million)**	
1	H	1998	180		100	
2	H+N	1989	200	2	120	
3	H+N	1985	240	20	30	75
4	N	1995	160	16.6		54.5
5	N	1984	146	16		57.5
6	N	1985	120	12		75
7	N	1983	384	23		51
Weighted mean				19.1*		60.7
Standard error				0.1		0.3

* Facility No. 2 was not included because its production is for research only.

Two nurseries are equipped with a tank to collect wastewater and allow for settling and/or treatment before discharge into the sea. All other facilities discharge wastewater directly into the sea. The same situation was observed in 1997 by Echavarría et al. (1998).

Table 6. Water treatment methods used**.**

Method	Number of hatcheries/nurseries reporting
Sand filter	5
Activated carbon	4
Chlorination	5
Cartridge filters	5
Ultraviolet lamp	5
Biofilter	1
Protein skimmer	1

Production Methods

The two largest hatcheries each produce 100 to 120 million nauplii per month. Their goal is to produce as much nauplii as possible to supply several farms. The hatchery run by Ceniacua is required to supply all Acuanal's members with nauplii, according to an agreement. The third hatchery/nursery surveyed produces just enough to meet the needs of its own farm. Nurseries surveyed produce on average 19 million PL (Table 5). Two of them belong to companies that also operate farms, and their priority is to supply their own farms. The other nurseries sell their product to any farm, even though there are trade agreements between certain nurseries and farms.

Recent survival rates in nurseries were 60%, on average (Table 5), higher than when nauplii were imported. Most managers reported that the improvement and stabilization of survival rates are two of the major benefits obtained from using locally produced nauplii.

Water abstraction is moderate, around 400 m^3/day on average, because volumes of water are limited (Table 5). Water abstraction is higher for hatcheries than for nurseries, because broodstock need more space and the water exchange rate needs to be higher, between 100–300%/day (Table 4), than for larvae. The production cycle starts with no water exchange for larvae; it is then progressively increased, up to 50–100%/day, depending on the nursery (Table 4).

Health Management and Biosecurity

Vibriosis is the most common pathology reported by managers (Table 7). Two managers reported managing it by increasing water exchange in culture tanks in order to reduce the density of pathogenic bacteria, allowing shrimp to resist the infection. Most managers, however, treated vibriosis with antibiotics, citing three antibiotics commonly used (Table 7). Some hatcheries or nurseries may use an antibiotic without any test results, but most of them would perform an antibiogram and also determine the minimum inhibitory concentration (MIC) to use. These tests are performed by the diagnostic lab run by Ceniacua. All managers who use antibiotics reported increasing resistance of bacteria to the antibiotics commonly used, especially oxytetracycline. One manager reported using probiotics for controlling vibriosis.

The Zoea II syndrome has been for several years the second most common pathology (Table 7), but its etiology was not known, and no specific treatment was applied. Another kind of pathology problem, cited by two managers, is protozoans (Table 7). They use formalin to treat the infection. Noninfectious pathologies reported include molting ("muda pegada") syndrome and deformities (Table 7).

Table 7. Main pathologies observed in the past and treatments applied in hatcheries and nurseries

Pathology	Managers reporting problem	Treatment	Managers reporting use
Vibriosis	6	Water exchange	2
		Furazolidone (antibiotic)	4
		Oxytetracycline (antibiotic)	4
		Chloramphenicol (antibiotic)	1
Zoea II syndrome	4	N/A	
Molting abnormality	2	N/A	
Deformities	2	N/A	
Protozoans	2	Formalin	2

N/A: no treatment available.

Managers also reported that disease is less of a problem with locally produced nauplii. The Zoea II syndrome that strongly affected nurseries from 1995 to 1997 has disappeared. Vibriosis has been decreasing but is still occurring in most facilities.

Because of the local seed production program, which the whole industry now relies on completely, and the threat of new pathogens such as the WSSV, it is of vital importance for the Colombian industry to protect itself from pathogens, especially viruses. Thus, producers have implemented biosecurity procedures developed mainly by Ceniacua. Biosecurity procedures apply to all facilities but logically focus on hatcheries and nurseries, since the contamination of any of them would quickly spread any pathogen to most farms. The Colombian biosecurity plan includes three primary strategies: (1) prevention of the introduction and circulation of pathogens, (2) early diagnosis of diseases, and (3) protection of the genetic stock.

Prevention of pathogen introduction and circulation applies at two levels: the Caribbean coast region and every individual facility. Since producers of the Caribbean coast have produced their own seed supply since 1999, this strategy aims to close the borders to any animal from a region where diseases are present (or may be). Producers are following the example of Venezuela, which was not hit by the Taura Syndrome thanks to their strict policy. The producers persuaded the Colombian government to pass a law that controls the importation and transportation from one coast to another of marine organisms.

Resolution No. 186 of June 1999 issued by the INPA (National Institute of Fisheries and Aquaculture) complements the measures included in the international health code of the IOE (International Organization of Epizootics), which requires a declaration of presence/absence of NHP, Baculovirus, IHHNV, TSV, WSSV, and YHV to export shrimp. Colombia is a member of the IOE. Resolution No. 186 requires a certificate of absence of the diseases mentioned in all frozen and live marine invertebrates, in order to authorize their importation. This measure also applies in Colombia for transportation of animals from one coast to another. The resolution also declares that inspections may be performed by the INPA and that any infected lot will be incinerated.

The export of shrimp from Colombia is also subject to the delivery of a health certificate by the INPA certifying that the facility has not experienced any unexplained mortality for at least 3 months and is free of NHP, Baculovirus, IHHNV, TSV, WSSV, and YHV, in agreement with IOE regulations. Even if artemia cysts, frozen polychaetes, and adult artemia imported from the USA for feeding larvae and brooders, are certified free of diseases according to INPA Resolution 186, Colombian hatcheries and nurseries check for the presence of WSSV by PCR before using any feed. Ceniacua also works to develop the use of locally available sources of feed, including a local strain of artemia.

Prevention of pathogen introduction and circulation at the facility level consists primarily of disinfecting any element that comes into contact with animals or circulates from one facility to another. This includes intake and outlet water, nauplii and post-larvae to be transported, boxes used in transportation, tires of vehicles, and clothes of the personnel. Any batch of larvae affected by an untreatable infectious disease would be destroyed entirely (with chlorine), and water and equipment that touched the animals would also be chlorinated. Hatcheries and nurseries plan their production to fill the facility within the shortest time possible (ideally 2–3 days), so that the larvae can be sold at the same time and all tanks and pipes can be emptied after every production cycle for a complete disinfection of the facility. One nursery manager noticed higher survival rate after they implemented a systematic and complete disinfection of the facility after each cycle.

A second aspect of the biosecurity plan focuses on the early detection of pathogens. Since WSSV is the major current threat for the industry, producers decided to ask each facility to check for the virus in each batch of animals to be transported to another facility. They ruled that nobody should receive any nauplii, post-larvae, or brooders without a certificate of the absence of WSSV, checked by PCR. In Colombia, three laboratories can perform this test using the PCR technique: Ceniacua (Cartagena), C.I. Oceanos (Cartagena), and Corpogen (Santafé de Bogotá).

All nauplii supplied by Ceniacua's hatchery have a pathogen-free certificate, with any pathogens detected by PCR for WSSV; Dot Blot for WSSV, TSV, NHP, and IHHNV; histology and microbiology. Any infected batch would be entirely destroyed by chlorinating the culture tank. Nurseries also perform tests periodically to survey the health status of cultured larvae, including stress challenges, microscopic observations, and identification of bacteria (Table 8). Vibriosis is the most common pathology. Two nursery managers also reported using survival checking as a tool to control health during the culture time.

A third aspect of biosecurity protects the genetic stock, a local strain of *L. vannamei* developed by selecting from the locally produced brooders. Ceniacua plans to build two biosecure facilities that would use totally closed cycles, allowing no entry of any live shrimp at any stage after initial stocking. Those facilities would therefore include reproduction, larviculture, and brooder production. Animals would be produced indoor in recirculating systems that include water disinfection. Those facilities would provide reserves of the local strain to start over if a disease outbreak occurs in farms. Ceniacua also works on the development of sperm cryopreservation techniques, also to preserve genetic material. This technique may provide other advantages to routine production, such as reducing the need to maintain male brooders, and allowing crosses between different generations of breeders.

Table 8. Diagnostic tests performed by the hatcheries and nurseries to check health status of shrimp

Test	Number of hatcheries/nurseries reporting:	
	Performed onsite	Performed by other lab
Stress challenge (salinity or temperature)	4	
Microscopic observations (wet mounts)	4	
Activity check	2	
Survival check	2	
Bacteria identification	1	3
Histology	1	
PCR for WSSV	1	6
Dot Blot for WSSV	1	
Dot Blot for TSV	1	
Dot Blot for NHP	1	
Dot Blot for IHHNV	1	

Use of Chemicals

Besides the drugs already mentioned above, hatcheries and nurseries use others chemicals on a regular basis (Table 9). Chlorine is used by all facilities surveyed to disinfect equipment and water. Total consumption of chlorine reported by managers (Table 9) was about twice that reported in 1997, as a consequence of implementing biosecurity plans.

Table 9. Drugs and chemicals used in the hatcheries and nurseries surveyed. (Dose per application and total consumption data are examples reported by some managers.)

Product	Uses	Number of facilities reporting	Dose per application	Consumption per year
Antibiotics				
Oxytetracycline	Bacterial infections	5	0.5 ppm in water	
Furazolidone	Bacterial infections	4	or 4000 ppm in feed	
Chloramphenicol	Bacterial infections	1	for 5 days	
Probiotics	Prevention of vibriosis	1		
Malachite green	Protozoa treatment	1		
Formalin	Protozoa treatment	3		
	Artemia cyst disinfecting	2		60–150 L
Sodium chloride	Artemia cyst decapsulation	2		11 kg
EDTA	Chelation of Iron	6	10 ppm	40–480 kg
Hydrochloric acid	Equipment disinfecting	3		432 L
Chlorine	Equipment disinfecting	7	200 ppm	6,300–12,000 L
	Water disinfecting	4	2–5 ppm	
Sodium thiosulfate	Chlorine neutralization	4		108 kg
Iodine	Equipment disinfecting	3		
	Eggs, nauplii disinfecting	1	10–50 ppm	
Calcium hypochlorite	Equipment disinfecting	1		
Sodium hydroxide	Equipment disinfecting	1		
Isopropyl alcohol	Equipment disinfecting	1		
Fertilizers	Microalgae culture	5		
Mineral and vitamin mix	Microalgae culture	5		

Facilities that use chlorine to treat water also add sodium thiosulfate to the water before its use to neutralize residual chloride. Iodine and hydrochloric acid (HCl) are the other most common products used to disinfect equipment. Disodium ethylenediamine tetraacetic acid (EDTA) is used as a metal chelator to prevent the deposition of iron precipitates on gills, which would cause mortalities. Soils are very rich in iron in the coastal areas, and runoff drains a large amount of iron into coastal waters after rainfalls, so this is a rather common problem. Total consumption of EDTA reported by managers in 2000 (Table 9) is about the same as 1997 values.

All facilities have closed rooms to store chemicals in safe conditions. Two managers reported not storing more chemicals than they needed for a month. All facilities keep records of the quantities of all chemicals used. None of the managers interviewed was aware of any list of drugs or chemicals with restricted use in Colombia. But they all know that such lists exist in other countries, and the US Food and Drug Administration (FDA) list was cited by one manager as a reference.

Employment and Personnel Management

Employment in hatcheries and nurseries is limited to 10 to 30 permanent positions per facility (Table 10). Hatcheries work almost entirely with permanent employees. Nurseries need additional labor for harvesting and so use contractors to provide labor on a temporary basis. Contractors work within a quite informal framework. Direct, friendly relationships between them and managers allow shrimp companies to rely on the same trained people year after year.

The majority (two-thirds on average) of employees and temporary personnel come from the surrounding areas, but the proportion is lower in hatcheries than in nurseries (Table 10), mainly because hatcheries don't use temporary personnel. As a consequence, labor use in hatcheries is usually less intense than in nurseries (Table 10). Hatcheries also tend to require more highly qualified personnel, who generally come from big cities, where education levels are higher than on the coast. Stability of personnel is high (Table 10) and correspondingly increases with the longevity of the company.

Table 10. Characteristics of employment in hatcheries (H) and nurseries (N) surveyed.

Facility	Activity	Number of employees				Contractors	Local employees	Duration	Labor use
		Managers	Workers	Contractors	Total labor	(%)	(%)	(years)	(man/m^3)
1	H	1	9		10	0	60	2	0.06
2	H+N	4	13	3	20	15	45	8	0.10
3	H+N	2	30		32	0	31	2	0.13
4	N	4	12	20	36	56	72	5	0.23
5	N	1	9	20	30	67	87	6	0.21
6	N	2	3	15	20	75	90	15	0.17
7	N	1	15		16	0	94	13	0.04
Weighted mean						35.4	67.1	6.8	0.12
Standard error						2.4	1.8	0.3	0.00

Companies provide personnel with necesary clothing (boots, coats) for their functions, as well as information on the safety rules and prevention procedures for production and biosecurity. Employees of all hatcheries and nurseries are given benefits along with salaries, including access to health care provided by the government, paid vacations, and participation in a retirement savings program. Five companies provide additional benefits to their employees, including bonuses, training and education, and food subsidies. Three companies reporting funding social programs in the community near the facility. Two of them are actually developed with the farms, which employ people from the same populations. The third hatchery provides access to a physician for families of employees and contributes financially to the village to support the school, the health care clinic, and the church, and also sponsors social events.

Economic Aspects

Acuanal estimated the average cost of producing PL at US$4.80/1,000 in 1995 (Table 11). At that time, nauplii were mainly imported from Panama, for a total cost (including transport) of US$0.90/1,000 (Arias, personal communication). The cost of nauplii was the single largest item, accounting for 37% of the total cost. Post-larvae were sold to local farms for a price of US$5.50–6.00/1,000. The margin for nurseries was then about US$1.00/1,000 PL.

Now that nauplii are produced locally, producers have agreed to sell them for US$0.60/1,000 and post-larvae at US$4.50/1,000 (plus 15% sales tax). When nurseries sell for export through Aquagen, they get a higher price of US$5.50–6.00/1,000 PL. According to information provided by Arias, the margin of nurseries seems to be about the same now as a few years ago. Therefore, total production costs were significantly reduced in Colombian nurseries, even though the price of artemia cysts quadrupled, making artemia the second largest cost.

The price of nauplii has decreased by 33% between 1995 and 2000, but nauplii still represent about 40% of the total cost of production (Arias). Simple calculations show that the reduction of about US$1.00 in the total production cost of PL from 1995 to 2000 could be attributed mainly to cheaper nauplii. Lower financing costs and better performance probably also contributed, because facilities are the same as they were 5 years ago, and managers reported a higher survival rate with local nauplii.

Artificial feeds and natural foods (polychaetes, artemia) are all imported directly by the producers from the USA. Formalin and EDTA were also originally imported, but producers now buy them locally.

Table 11. Distribution of the production costs for Colombian shrimp nurseries in 1995

	Cost per thousand PL produced	
	(US$)	**(% of total)**
Nauplii	1.77	36.9
Feeds	0.35	7.3
Drugs and chemicals	0.12	2.5
Labor	0.81	16.9
Maintenance	0.20	4.2
Transport and other services	0.05	1.0
Administration	0.30	6.3
Subtotal, direct costs	3.60	75.0
Indirect costs	0.82	17.1
Financing	0.38	7.9
Total	4.80	100.0

Source: Acuanal.

Grow-out Farms

All farms were built in the 1980s. The slight increase in production area observed during the 1990s (Figure 2) was due to the expansion of already existing farms. The decrease in production area observed in 1997 (Figure 2) resulted from the closure of some facilities from the bankrupcy or voluntary sale of a few companies. High mortality rates from Taura Syndrome led to these financial problems.

Design and Construction

An environmental license must be obtained from the Regional Autonomous Corporation (the local environmental authority) to build any new facility or to expand any existing operation beyond what was planned and approved. Each company has to submit an Environmental Impact Assessment (EIA) as well as an environmental management plan as established by Decree 1753 of 1994. The environmental authority can refuse any proposed work or impose modifications of procedures or additional remedial measures. Compliance with the environmental management plan is reviewed by the local environmental authority, which visits each facility on an annual basis.

Managers stated that the criteria for selecting sites included the following (ranked by number of mentions):

1. Availability of fresh water (it was believed that salinity control was a key factor in shrimp culture)
2. Topography
3. Soil texture
4. Access by road
5. Natural richness of supply waters
6. Labor availability
7. Cost of land
8. Availability of undeveloped land

All managers declared that labor availability was assured on selected sites by the proximity of villages, where job opportunities never match the rate of population growth.
The EIAs addressed the following issues:

1. Hydrology and water quality
2. Topography and soil quality
3. Climate
4. Fauna and flora

The environmental management plans also describe and analyze the following:

1. Construction and operations
2. Costs and benefits
3. Risk analysis and management
4. Social and environmental impacts
5. Mitigation measures for impacts
6. Contingency plan
7. Security

The initial EIAs were strictly descriptive and considered only the state of the ecosystem before construction. The environmental plans are required to evaluate impacts and to propose mitigation measures. Therefore, many issues that should have been included in the original EIAs are now being addressed.

In Colombia, any unauthorized mangrove cutting is prohibited by law. Farm owners have to obtain a special authorization to clear mangrove, even in very limited areas, for building inlet and/or outlet canals. For example, one company has been required to plant 5 ha of mangrove for each single ha of mangrove cleared. The company also obtained a special authorization to cut mangrove trees in order to maintain water circulation in natural channels around its farm, which is located in an estuarine area. In all cases, the environmental authority requires that farmers manage mangroves to avoid any net loss. Once all EIAs and environmental management plans have been approved, a "culture permit" is granted by the National Institute of Fisheries and Aquaculture (INPA) allowing operations to begin. A pumping permit must also be obtained from the Maritime Administration. The latter authority also delivers concessions for canal entrances and exits, and for decks, docks, or any construction near the coast. This is because the intertidal zone and a buffer zone 50 m wide along the coast belong to the Nation and cannot be owned in any way by individuals.

The company Tropical Mariculture Technology (USA) has designed three surveyed farms, and France Aquaculture designed another one. The other farms were designed by the owners. The construction of all farms was managed by Colombian engineers, either employees of the aquaculture company or those working for a public works company.

All farms were built on private lands. Nevertheless, two farms have a small concession corresponding to canal entrances and/or exits. Of six companies surveyed, five own the land, and the other rents it (Table 12). Most of the sites owned by shrimp companies were previously agricultural land (Table 12) occupied by extensive cattle ranches that generated a few jobs, or land that simply remained undeveloped. No indigenous populations were established on any of these areas. A significant proportion of the lands (34.7%) were areas of transition between a fringe of mangrove and terrestrial vegetation. These plots were influenced by high tides where only some halophytic plants could grow, so they were not developed. Another 17.6% of the land is mangrove forest. It is possible to own mangroves in Colombia, when they extend beyond the fringe of 50 m along the coast. Increasingly, mangrove trees colonize private lands on which they were not present at initial purchase. Mangrove ecosystems included in the farms have been preserved entirely, since they are protected by the law, except for authorized cuttings. About 32 ha of mangrove have been cleared in the farms surveyed, which is equivalent to 12.1% of the total mangrove included in farms' property (Table 12). All farms, with the exception of one that does not own any mangrove, have a planting program. All of them planted mangrove seedlings on the edges of canals and ponds, and some also planted on undeveloped areas.

The texture of the soil is highly variable from one farm to another. Clay content is very high (about 50%) at two farms located in sedimentation areas but very low (2.5%) at a farm built on former cattle lands (Table 12). The original soil pH was neutral or slightly acidic for most farms. A farm located in an arid area had a lower pH, around 5. Four farms were built on high ground, while the other two farms are located in a low-lying sedimentation area (Table 13). The pond bottom is even lower than the sea level in one farm, and water has to be pumped to totally drain the ponds.

The productive area is very variable across farms (Table 13). The two biggest companies own 55% of the total pond area currently in operation in the Caribbean coast (Tables 2a and 13). The biggest company actually owns farms that have 412, 230, 19, and 15 ha of ponds. On average, ponds represent only 33% of the total area owned by farms. Four farms produce brooders and thus are responsible for protecting genetic lines on which the whole industry now relies. The manager of a fifth farm indicated his team is considering producing brooders soon. The four farms dedicate a total of 39.5 ha to the culture of brooders (Table 13), which represents 2.6% of the total pond area they operate. Together, the four farms produce about 50,000 brooders per year, which are sold to local hatcheries.

Table 12. Characteristics of the sites on which surveyed farms were built

Farm	Property		Soil type		Land type			Mangrove		
	Total area (ha)	Ownership (%)	Clay content (%)	PH	Agricultural (%)	Transition (%)	Mangrove (%)	Area cleared (ha)	Area cleared (%)	planting
1	334	99	47.5	5	99	0	1	2	59.9	yes
2	243	98	55	6.5	98	2	0	0	0.0	no
3	2373	100	25	6	0	77	23	0.5	0.1	yes
4	480	0	25	6	95	0	5	20	83.3	yes
5	570	100	20	7	75	5	20	8	7.0	yes
6	1369.5	100	2.5	7	81	0	19	1.6	0.6	yes
Weighted mean		90.9	21.5	6.3	47.7	34.7	17.6		12.1	
Standard Error		0.4	0.2	0.0	0.6	0.5	0.1		0.4	

Table 13. Characteristics of ponds in the farms surveyed

Farm	Productive area		Broodstock ponds		Pond characteristics			Effluent treatment method
	(ha)	**(% of property)**	**(ha)**	**(% of total ponds)**	**Mean Area** (ha)	**Mean Depth** (m)	**Mark above sea level** (m)	
1	122	37	6	4.9	4	1	3	Sediment traps
2	90	37	—	—	5.6	1	2.5	None
3	674	28	24	3.6	8	1.2	-0.2	None
4	160	33	—	—	8.8	0.9	0.2	None
5	422	74	5.5	1.3	9	1.4	3	None
6	286	21	4	1.4	6.5	1.3	4.3	Settling canal, mangrove biofilter
Weighted mean		32.7			7.7	1.2	1.7	
Standard Error		0.2			0.0	0.0	0.0	

All farms were designed with separate inlet and outlet canals, and all ponds have separate entrance and exit structures. Two farms were designed to support effluent treatment. One farm includes sediment traps in the discharge canal: concrete structures that slow the water flow and allow particles to settle. The traps are cleaned periodically. Another farm incorporates sediment traps in the discharge canal and an additional 1-km long canal to allow further settling. It is cleaned periodically by mechanical dredge. This canal brings discharged water to a mangrove area that is used as a biofilter (Gautier 2000). Yet another farm built sediment traps in the inlet canal. All inlet canals were designed (width, depth, and slope) to avoid erosion and to allow settling. Sedimentation of soil particles from natural waters in inlet canals is actually a common problem in all farms. Inlet canals are dredged periodically to maintain their overall capacity.

Pond Preparation

Pond preparation begins just after harvesting with a "soil wash"—flushing the upper layer of semiliquid sediment out of the pond. This is usually done by hand with some rudimentary implement, by pushing the sediment into a small water flow. Two farms wash their soils in this way after harvest (Table 14).

The next phase of pond preparation is to dry the bottom. (All other actions are performed only after the soil bottom has dried.) Drying is done before every production cycle at half of the farms surveyed, and once every two cycles at the remainder of the farms (Table 14). Some shrimp farmers prefer not to prepare the pond soil during the rainy season, because the bottom does not dry well. The drying time is very variable, averaging about 4 weeks. One farm lets the pond bottom dry for about four months; they perform two successive cycles and then stop production from November until February.

All farms but one disinfect the pond bottom to kill pathogens present in the pond in order to prevent the transmission of diseases to the next crop. Applying burnt lime ($Ca(OH)_2$) on the bottom raises the pH to a level of about 10 and kills all life (Boyd 1995). Some farms apply burnt lime only in the areas where organic detritus has accumulated.

Table 14. Pond preparation methods in the farms surveyed

Farm	Soil wash	Drying frequency (per cycle)	Drying duration (days)	Tilling	Disinfecting	Liming (kg/ha)	Organic fertilization (kg/ha)	Inorganic fertilization (kg/ha)
1	yes	0.5	40	yes	yes	1200	50	25
2	no	0.5	150	yes	yes	1500	0	0
3	no	1	15	yes	yes	1000	400	0
4	no	1	28	yes	no	1800	400	0
5	yes	0.5	30	yes	yes	700	150	0
6	no	1	10	yes	yes	1000	1000	0
Weighted mean			27.6			1040	393	1.7
Standard Error			0.7			7	7	0.2

Table 16. Production results in the farms surveyed

Farm	PL age at stocking (days)	Acclimation time on site (days)	Stocking density (PL/m^2)	Growth rate (g/week)	Survival rate (%)	Harvest size (g)	Cycle duration (days)	Yield per cycle (kg/ha)	Carrying capacity (kg/ha)	Number of cycles per year	Total production (tons/year)
1	9–35	0.1	28	0.7	66	11.5	130	1664	2600	2.5	500
2	8–13	0	17	0.8	57	12	100	1218	-	2	192
3	11-13	0.1	16	0.92	66	13.9	105	1466	2000	2.7	2588
4	10	0.1	17	0.9	65	15.5	120	1650	2500	2	445
5	10	1.5	22	0.7	65	11	120	1700	-	2.8	1600
6	10–30	0.2–20	22	0.87	65	12.5	120	2047	2800	2.2	1250
Weighted mean	11.7	3.7	19.4	0.84	65.1	12.8	114	1654	2318	2.6	
Standard Error	0.1	0.2	0.1	0.00	0.0	0.0	0.1	3	5	0.0	

Table 15. Scale used by Oceanos to define liming rate as a function of soil pH.

Soil pH	Liming rate (kg/ha)
< 5.0	2000
≤ 5.0 < 5.4	1800
≤ 5.4 < 5.6	1600
≤ 5.6 < 5.8	1400
≤ 5.8 < 6.0	1200
≤ 6.0 < 6.2	1000
≤ 6.2 < 6.8	700
≤ 6.8 < 7.0	100
> 7.0	0

Source: Courtesy of Remolina (C.I. Oceanos).

All farms also lime the pond bottom with agricultural lime ($CaCO_3$) to manage the soil pH. The purpose of liming is to raise the soil pH to about 8, to enhance microbial activity and thus stimulate the degradation of organic detritus that accumulated during the previous crop. Liming is ideally performed when the bottom is still wet, because some humidity is required for microbial activity (Boyd 1995). Technicians measure the soil pH after harvesting and calculate the amount of lime to apply according to a scale recommended by Boyd (see Table 15).

All farms till the soil as soon as possible, i.e., when the soil is dry enough to withstand the weight of a tractor. The purpose is to aerate the soil to stimulate microbial activity (Boyd 1995). Shrimp farmers use tractor-powered rototillers or disk harrows. Sometimes, they also pull a tooth harrow to smooth the surface after aeration and to further mix in the lime that has been added.

All farms but one apply fertilizer to the bottom before flooding the pond. Three farms use soybean meal and chicken feed together. Two farms use chicken manure in combination with other products. One farm also uses palm by-products. Urea is applied at one farm, which also applies inorganic fertilizers (nitrate calcium and triple superphosphate). The rates of application are highly variable from one farm to another (Table 14), and even between ponds in the same farm depending on soil conditions evaluated by the technical staff. The objective of organic fertilization is to stimulate the development of benthic organisms during the first days of filling the pond, which provides a source of natural food to shrimp PL. Farmers look for inexpensive organic products that are rich in protein, so they are either quickly transformed by bacteria or ingested and digested efficiently by benthic animals.

Finally, the last component of pond preparation consists of placing fine meshes at the entrance and exit structures, to prevent the entrance of predators, competitors, or pathogen carriers into the pond, and prevent the escape of shrimp stocked in the pond, respectively. A series of two to three meshes is placed at each structure. The finest mesh used during the first weeks of culture is a 500-µm mesh. After a few weeks of culture, when the water exchange rate increases, the finest mesh used is a 1-mm mesh. Meshes are cleaned frequently (several times a day) to ensure the appropriate water flow. Even so, small plankton that may include larval forms of possible predators or competitors (fish or crustaceans) and certain pathogens can pass through the meshes.

Production Methods

All Colombian shrimp farms now use 100% locally produced PL, though in 1997 only about 25% were produced locally (Figure 6). Farms stock 12-day-old PL on average (Table 16). Only two farms stock larger PL from time to time. In one case, PL are first grown for a while in outdoor tanks in the nursery. Another farm puts its PL in concrete tanks for over 20 days for this first stage (included in acclimation time in Table 16). The purpose of this step is to stock larger PL in the grow-out ponds that are more resistant to disease and stress and to obtain improved and more predictable survival rates.

All farms but one acclimate PL on site. The single exception asks the suppliers to acclimate PL to the farm's salinity. Nevertheless, a temperature acclimation is performed on site by letting the PLs bags float in pond water for less than an hour, until their water temperature equilibrates. All other farms use a specific facility to acclimate PL. It is either fixed, with concrete tanks at two farms, or portable. The portable system consists of a fiberglass tank equipped with an oxygen tank and a shading device. Acclimation tanks are filled with the same water that is used in the ponds. Acclimation usually takes only a few hours (Table 16), depending on differences in water characteristics between the nursery and the farm. One farm acclimates PLs systematically for 24 to 48 hours.

In 2000, stocking density is similar in most farms, with an average of 19.4 PL/m² (Table 16), in contrast to 1997's figure of 29.6 PL/m² (Figure 6). This higher 1997 stocking rate stems from the Taura Syndrome outbreaks that caused low survival rates, about 50% on average. Farms used to stock ponds at high density to compensate for the expected mortality that mostly occurred within the first month of culture. Survival rates are now 65% on average, so farmers decreased stocking density so as not to harm growth. Farmers have observed the relationship between stocking density and growth. As a matter of fact, Table 16 shows that farms that stock at higher density have longer production cycles and/or smaller harvest size than farms that stock at lower density.

Farmers also learned that carrying capacity is site-specific, even if they are not always able to give an exact value for their own farm (Table 16). The carrying capacity of each site is reflected in the average yield obtained per cycle, which ranges from 1,200–2,000 kg/ha. Average yields have increased only slightly when compared to 1997 (Figure 6). Considering the large differences in survival rate and stocking density between the two years, this demonstrates how well farmers know the carrying capacity of their ponds and are able to control the standing crop to obtain the desired harvest size.

Another interesting trend is a decrease in the number of cycles per year, from 2.8 to 2.6 between 1997 and 2000 (Figure 6). Farmers tend to stop stocking PL during the last quarter of the year, which has the most rainfall. With a cycle duration of 110 to 120 days, plus 20 days of preparation, all farms could produce 2.6 to 2.8 cycles per year. But two of the farms surveyed have already decided to run only 2 cycles per year and simply dry the farm for several months, instead of producing in bad conditions. These farmers believe that it makes the farm more sustainable on a long-term basis, even if production is lower for about the same fixed costs and overall profit margins are lower. These farms are thoroughly dried to eliminate vectors of diseases and better maintain their facilities. Other farms are voluntarily reducing the number of crops produced each year with the same objective, even if they still produce more than 2 crops per year on average (Table 16).

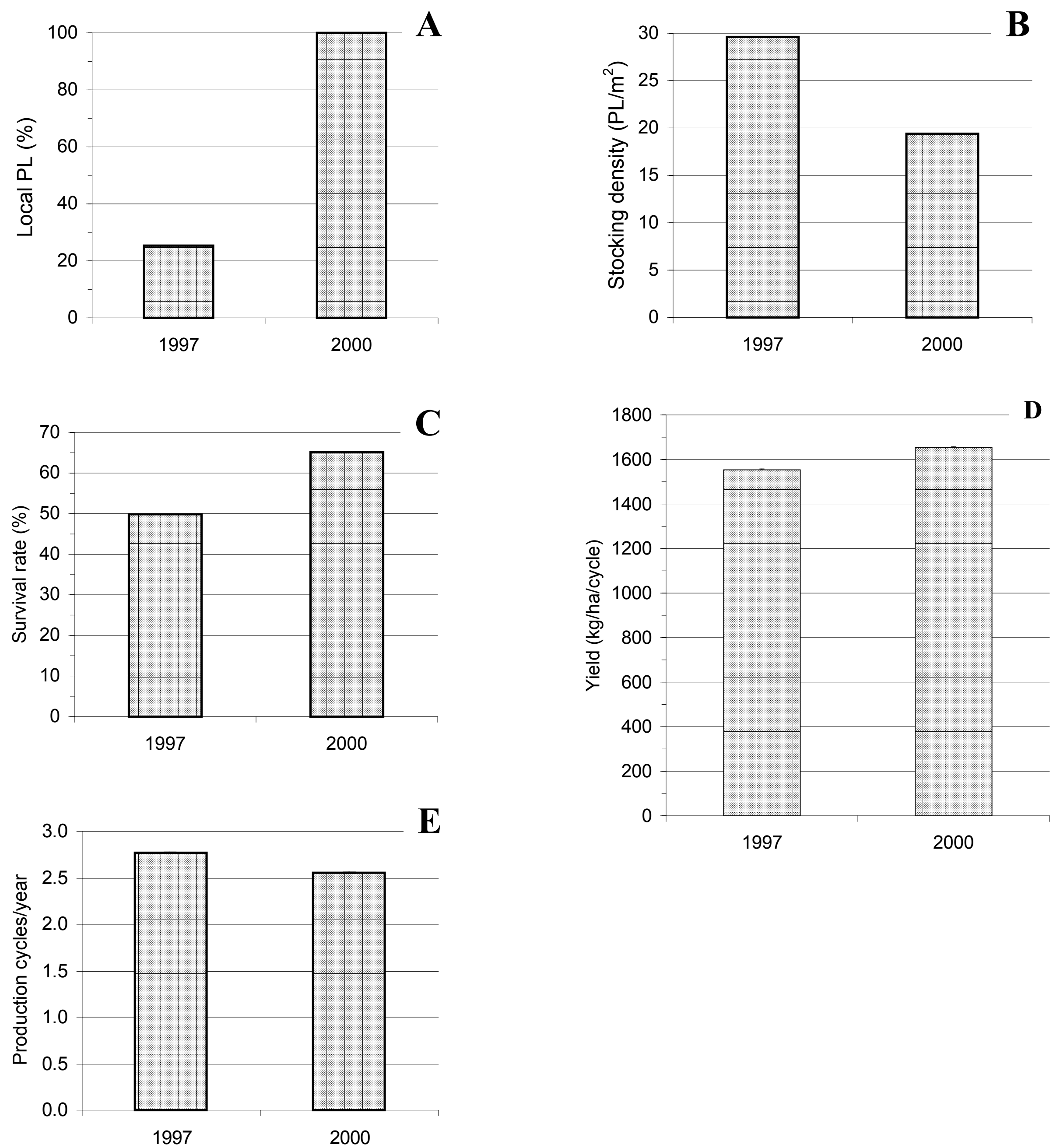


Figure 6. Comparison of production characteristics in 1997 and 2000 of shrimp farms along the Caribbean coast (mean values). Percentage of local PL stocked in production ponds (A), stocking density in production ponds (B), survival rate in production ponds (C), shrimp yield obtained per production cycle (D), number of production cycles performed within a year (E).

Resource Use and Feed Conversion Efficiency

The volume of water used per ton of shrimp produced decreased significantly from 1997 to 2000 (Figure 7). Consequently, diesel consumption also decreased (Figure 7). However, the use of both inputs varies considerably from farm to farm (Table 17). Differences are partially explained by site-specific characteristics such as evaporation and seepage, and also by shrimp yields. Water exchange rates were drastically reduced since 1997, from 12% to 5% on average in 2000 (Figure 7). Farmers reacted to pressure from international and governmental agencies on the effluent issue. In addition, data from other countries demonstrated that semi-intensive shrimp ponds could be run with no or very limited water exchange without negative consequences on production. Farmers realized they could lower production costs while doing something positive for the environment by using less water.

Feeds are another major input. The apparent feed conversion ratio (FCR) was 1.41 on average in 2000 (Table 18), about the same as in 1997 (Figure 7). Feed is provided based on the estimated shrimp weight in the ponds. The fact that the same low FCR was reported in 1997 when high mortality rates made management decisions more complicated shows that Colombian farmers manage feeding very precise. Weekly shrimp samples provide estimates of weight and population density. The total shrimp weight is then used to find the daily feeding rate on a feeding table. The daily ration is fed during the daytime, 2 to 5 times a day depending on the operation. All farms use feeding trays to sample and monitor shrimp feeding activity. A scale quantifying feeding activity allows staff to correct the amount of feed used. Some farms feed entire ponds with feeding trays, but most farmers report that they abandoned this method because it requires more labor and did not produce any gain in either FCR or growth.

In addition to feed, organic and inorganic fertilizers are applied to stimulate the development of phytoplankton and the food web in general. Some fertilizers are applied when preparing the soil, and others are applied to the water during the culture period. Application rates vary depending on the farm (Table 18). On average, 0.36 and 0.38 kg of organic and inorganic fertilizers, respectively, are used to produce 1 kg of shrimp. When these amounts are added to 1.41 kg of feed (FCR), the total apparent nutrient conversion ratio is 2.15:1. On average, the use of fertilizers decreased by 16%, comparing the 1997 and 2000 rates of application per ha and per cycle.

Table 17. Water and diesel use in the farms surveyed

Farm	Salinity of supply water		Water pumping		Water exchange	Diesel consumption	Input efficiency	
	Min. (‰)	Max. (‰)	Head (m)	Abstraction (m^3/day)	(%/day)	(m^3/year)	Diesel (m^3/ton)	Water (m^3/ton)
1	0	40	4	300000	7.5	499	1.00	219000
2	0	30	3	18900	2	45	0.24	35930
3	20	32	3.3	1294920	5	956	0.37	182637
4	0	36	2	na	7.5	207	0.47	na
5	20	35	9	1209600	4	1588	0.99	275940
6	0	32	7.5	350000	7	540	0.43	102200
Weighted mean	15.8	33.9	6.0	867519	5.3	893	0.58	188959
Standard Error	0.0	0.0	0.0	231403	0.0	11	0.00	841

na: not available.

Table 18. Nutrient input and conversion rates in the farms surveyed

Farm	Pelleted feeds			Organic fertilizers			Inorganic fertilizers		
	(kg/ha/cycle)	(tons/year)	Conversion	(kg/ha/cycle)	(tons/year)	Conversion	(kg/ha/cycle)	(tons/year)	Conversion
1	2829	850	1.70	50	214	0.43	45	7	0.01
2	1523	238	1.24	100	3.6	0.02	543	28	0.15
3	1742	3289	1.27	673	1270	0.49	668	1261	0.49
4	2188	700	1.57	673	215	0.48	668	214	0.48
5	2550	2400	1.50	150	63.3	0.04	86	1016	0.64
6	3071	1800	1.44	1045	600	0.48	0	0	0.00
Weighted mean	2258.2	2270	1.41	535	635.8	0.36	369	750.4	0.38
Standard Error	12.7	24	0.00	8	12.7	0.00	7	13.1	0.00

Note: Calculations of fertilization rates include fertilizers applied during pond preparation and the culture period.

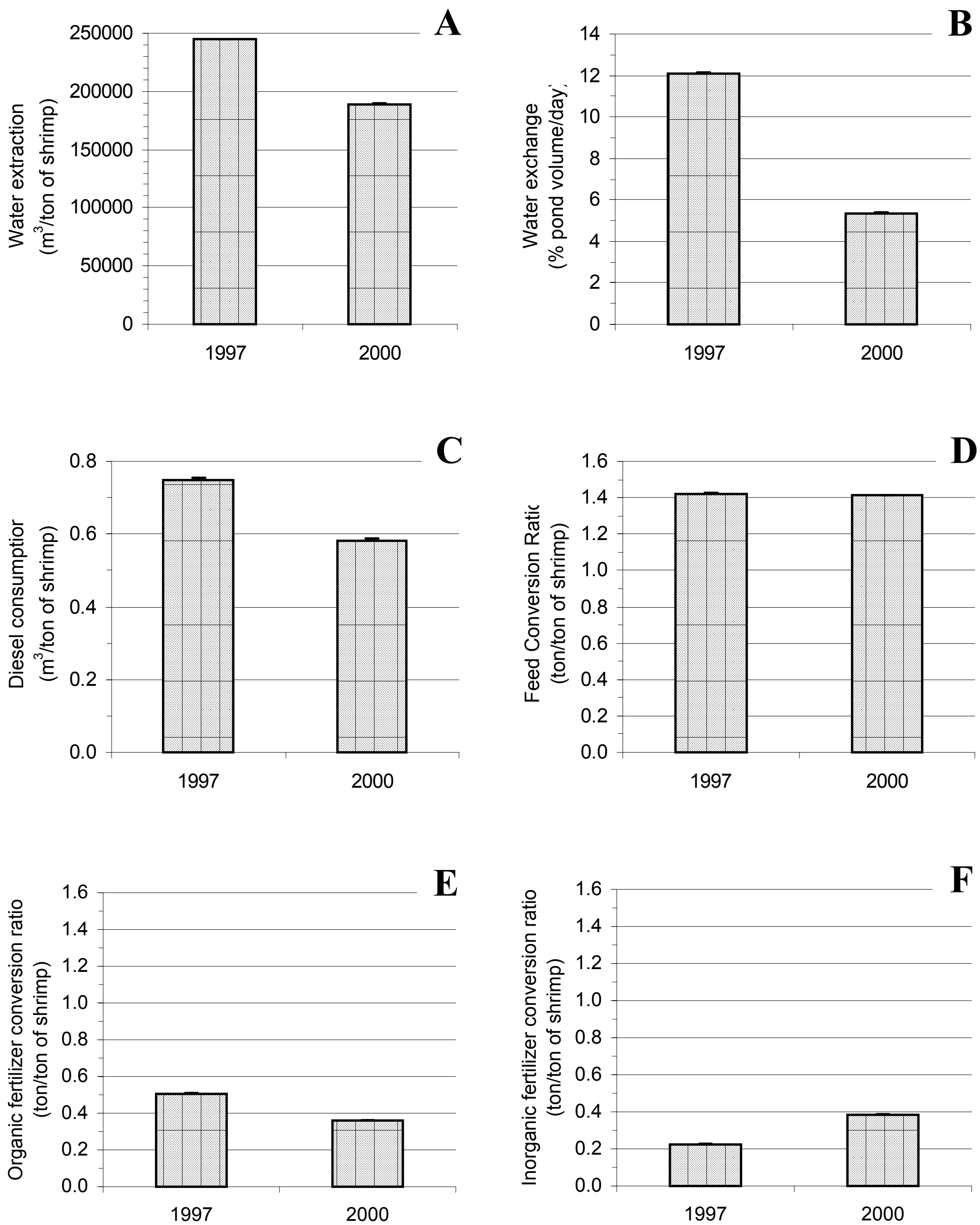


Figure 7. Comparison of input consumption and conversion in 1997 and 2000 of shrimp farms along the Caribbean coast (mean values). Volume of water pumped per ton of shrimp produced (A), daily water exchange rate in production ponds (B), volume of diesel fuel consumed per ton of shrimp produced (C), amount of feed consumed per unit of shrimp produced (D), amount of organic fertilizers consumed per unit of shrimp produced (E), and amount of inorganic fertilizers consumed per unit of shrimp produced (F).

In fact, the amount of organic fertilizer used was diminished by 29% (mostly because some farms abandoned the use of chicken manure), while inorganic fertilizers increased by 14%. As a consequence, the conversion rate of organic fertilizers has improved from 1997 to 2000, while the conversion rate of inorganic fertilizers has gotten worse (Figure 7). Some farms base the rate of application of inorganic fertilizers on the actual concentration of inorganic nutrients measured weekly in ponds. Other farms apply inorganic fertilizers based on the growth of plankton density.

Water Quality Control

All farms surveyed are equipped with a small laboratory to monitor basic water quality, focusing on water quality in the ponds (Table 19). Temperature and dissolved oxygen (DO) are the only parameters that all the farms surveyed measure every day (Table 19). They measure these parameters early in the morning (around 6 a.m.), when DO should be at its minimum level. In case of dangerously low DO levels, all managers reported that they increase the rate of water exchange. Two managers reported using emergency aeration with paddle-wheel aerators driven by the power take-off (PTO) of farm tractors. Four farms also check temperature and DO in the afternoon, when levels are likely the highest.

All farms but one measure nutrients in ponds weekly or every two weeks (Table 19). Managers evaluate the fertility of the pond water and apply fertilizers if needed. One farm reported a very well-established program of weekly fertilization based on the concentration of inorganic nutrients (N, P and Si) measured. Its managers' goal is to maintain a set concentration of nutrients that they believe will produce a good plankton bloom. Farmers try to support the growth of diatoms. Four farms measure the density of plankton populations on a weekly basis (Table 19), as a tool to modify their fertilization program.

Four farms reported having protocols to monitor the quality of the water supply (Table 19). They usually monitor water quality to determine possible effects of pumped water on water quality in ponds. The same farms also monitor water quality in the discharge canals.

Colombian Law 99 of 1993, which created the Ministry of the Environment, defined the principles for applying taxes on waste discharge. This law applies to waste waters from any point source of contamination, as specified by Decree 901 of 1997. Autonomous Regional Corporations (ARCs, the environmental authority in each administrative department of the country) have the responsibility to enforce this environmental tax legislation, based on effluent quality monitoring. For aquaculture, the parameters involved are Biochemical Oxygen Demand (BOD_5 in mg/l) and Total Suspended Solids (TSS in mg/l). These are also the most common parameters considered in other countries (Boyd 1997). All farms surveyed reported that the ARCs had started to monitor the quality of their effluents on a monthly basis. Managers reported that the ARCs intend to use the effluent measures to compare BOD_5 and TSS concentrations in the supply water and the effluent. A tax is charged only if contaminant loads are higher in discharge water than in supply water. The tax is currently 58 and 25 Colombian pesos (US$1.00= 2,000 pesos) per kg of BOD_5 and TSS discharged, respectively.

First results of effluent monitoring from the farm that uses mangrove as a biofilter to treat discharged waters (Gautier 2000) showed maximum values of BOD_5 and TSS of 4 and 15 mg/l, respectively. These values are 70% and 51% *lower* than in the supply water, respectively. A 14-month monitoring record from another farm indicated average TSS concentrations of 114, 56, and 193 mg/l in supply water, discharged water, and the receiving water body, respectively. Average BOD_5 values in the same farm were 3.25, 3.95, and 2.67 mg/l, respectively. This last farm is located in the Isla del Covado, an area strongly influenced by the Magdalena River, which discharges huge amounts of sediments. In this situation, the farm appears to be a site where suspended solids settle. Those solids are probably mostly inorganic particles, considering the low BOD_5 values reported. A slight increase in BOD_5 is caused by the farm's operations.

Four farms monitor the same parameters as the ARCs (Table 19). A few farms also measure other parameters in their discharge canal to try to obtain a better understanding of the processes going on in their farm and the overall effect of management practices on water quality.

Table 19. Water quality monitoring measures used in the farms surveyed.

Measure	Number of farms reporting				
	At least twice a day	Daily	Weekly	Biweekly	Monthly
Supply water					
Temperature		3			
Dissolved oxygen		3			
pH		3			
Salinity		3		1	1
Alkalinity				1	1
Ammonia		1		1	1
Nitrate		1		1	1
Phosphate		1		1	1
Silicate		1		1	1
Phytozooplankton				1	1
Pond water					
Temperature	4	2			
Dissolved oxygen	4	2			
pH	3	1	1		
Salinity	2	2	1		
Secchi disk visibility		2			
Alkalinity			2	2	
Ammonia			3	2	
Nitrate			3	2	
Nitrite			2		
Phosphate			3	2	
Silicate			3	2	
Phytozooplankton			4		
Discharge water					
Temperature		2	1		1
Dissolved oxygen		2	1		2
pH		2	1		2
Salinity		2	1		2
Conductivity			1		1
Ammonia		1	1		2
Nitrate		1	1		2
Nitrite			1		2
Phosphate		1	1		2
Silicate		1	1		1
Phytozooplankton					1
BOD_5			1		3
COD			1		1
Total suspended solids			1		3
Volatile suspended solids					1
Settlable solids			1		1
Oils and greases					2

Health Management and Biosecurity

No major disease is currently reported at the farm. Only vibriosis is reported as a chronic pathology by a few farms (Table 20), but not all the farms monitor *Vibrios* (Table 21) and so may not be able to detect it when it first occurs. All farms surveyed reported having experienced Taura Syndrome between 1995 and 1997. Other diseases that have appeared are NHP, rickettsia, and IHHNV. All managers noted that the occurrence of diseases has drastically decreased with stocking locally produced seed (reflected in the improved survival rate) (Figure 6). Only one farm reported using antibiotics to treat vibriosis (Table 20). They use oxytetracycline after checking its effectiveness with an antibiogram performed by the diagnostic lab run by Ceniacua. This manager reported that the farm's staff has not observed any resistance to the antibiotic. No other treatment or specific management techniques are used to fight disease. It appears that producers have concluded that the best way to prevent disease is breeding animals that have survived in their own farms, assuming that the next generation would be more resistant to pathogens.

Farmers have developed biosecurity procedures to prevent diseases from appearing. First, steps are taken to prevent the introduction of pathogens to the farms. Since WSSV is the major threat, farms do not receive any PL without a certificate that the PL are virus-free, sustained by PCR test. Post-larvae packaging is washed and disinfected with chlorine before entering the farm, and also before leaving the farm. Vehicle wheels are also disinfected before vehicles enter a farm. To gain entrance, visitors must not have been at another farm in the last four days. Disinfection of all materials used in ponds is performed routinely. Any dead animal recovered from a farm is incinerated.

A second aspect of biosecurity concerns early diagnosis of diseases, with the effort focused on WSSV. All farms but one monitor cultured shrimp by PCR (Table 21). A PCR certificate is mandatory for brooders to be moved to another facility (for the four farms that grow brooders). The only farm that owns PCR equipment also monitors on a weekly basis the natural populations of crustaceans present in their facility. All farms perform a stress challenge with the PL to be stocked (Table 21), a procedure implemented since the beginning, as an effective method of evaluating PL quality. Actually, two farms ask the supplier to perform it for them. The stress test is actually performed more for production reasons than for biosecurity. Four farms perform routine check-ups of gills, hepatopancreas, or other organs by means of wet mounts (Table 21). The biggest farms also use microbiology, histology, and newly available genetic probes to monitor the presence of known pathogens.

One farm has a written contingency plan in case of WSS outbreak; inspired by experiences in Asia, it includes a program of trials for modified pond management. Other farms are confident in the prevention policy established by the industry to avoid WSSV. All managers think they are well informed about disease evolution and management, through Ceniacua, personal contacts, assistance obtained from international conferences, and Dr. J. Brock (Hawaii), whom Ceniacua has under contract as an advisor.

Table 20. Main diseases experienced in the farms surveyed. (Only vibriosis is currently reported.)

Disease	Number of farms reporting	Treatment	Number of farms reporting
Taura syndrome	6		
Vibriosis	3	Antibiotic	1
NHP	3		
Rickettsia-like bacteria	1		
IHHNV	1		

Table 21. Tests and diagnostic methods used in the farms surveyed to check health status of cultured shrimp

Test	Number of farms reporting:	
	Performed on site	**Performed by other lab**
Stress challenge (salinity or temperature)	4	2
Microscopic observations (wet mounts)	4	
Bacteria identification	2	1
Histology	1	1
PCR for WSSV	1	4
Dot Blot for WSSV	1	
Dot Blot for TSV	1	1
Dot Blot for NHP	1	1
Dot Blot for IHHNV	1	2

Employment and Personnel Management

The six farms surveyed employ a total of 1,013 people (Table 22). Labor use per ha of pond increased 15% between 1997 and 2000, to 6.1 men/ha (Figure 8). Farmers hired additional operations workers. Management personnel levels (including executives and administrators) are roughly the same as three years ago and now represent a lower proportion of the total personnel. The year 1997 was a period of financial difficulties for most farms because of the high mortality from disease that started in 1995. Personnel was then limited to the minimum required to keep the farms in operation. Production per employee was thus almost 2 MT of shrimp higher in 1997 than in 2000 (Figure 8).

The overall increase in personnel was oriented towards temporary workers hired by contractors, rather than permanent employees. Contractors are more important in 2000 than in 1997, currently providing 40% of the total labor (Table 22). Contractors provide labor for all activities that require manual workers for a short period of time, such as construction, harvesting, and pond preparation. Contractors hire only local people. The proportion of the total that is local labor (almost 80%) has not changed between 1997 and 2000 (Figure 8).

Personnel stability is high on all farms (Table 22), reported as almost equal to the life of the companies. Average duration of employees is about 3 years more in 2000 than in 1997, demonstrating that most have stayed at the same farm. Farmers indicated that personnel provided by contractors are also retained at very high rates.

Since farms employ many people who come from a few villages, farms provide the main source of income for these people, who used to eke out small incomes from traditional fisheries, mangrove exploitation, or extensive agriculture and ranching. As an example, 50–60% of the workers living in the four main villages located around Covado Island near Cartagena work in shrimp farms. Additionally, small rural villages suffer from a lack of public services of all kinds. On the other hand, surrounding villages are the best source of stable labor for shrimp farms. Shrimp ponds also provide temptation for thieves. For all these reasons, shrimp companies have a responsibility (and an interest), in ascertaining the welfare of their employees and in improving the living conditions of surrounding populations.

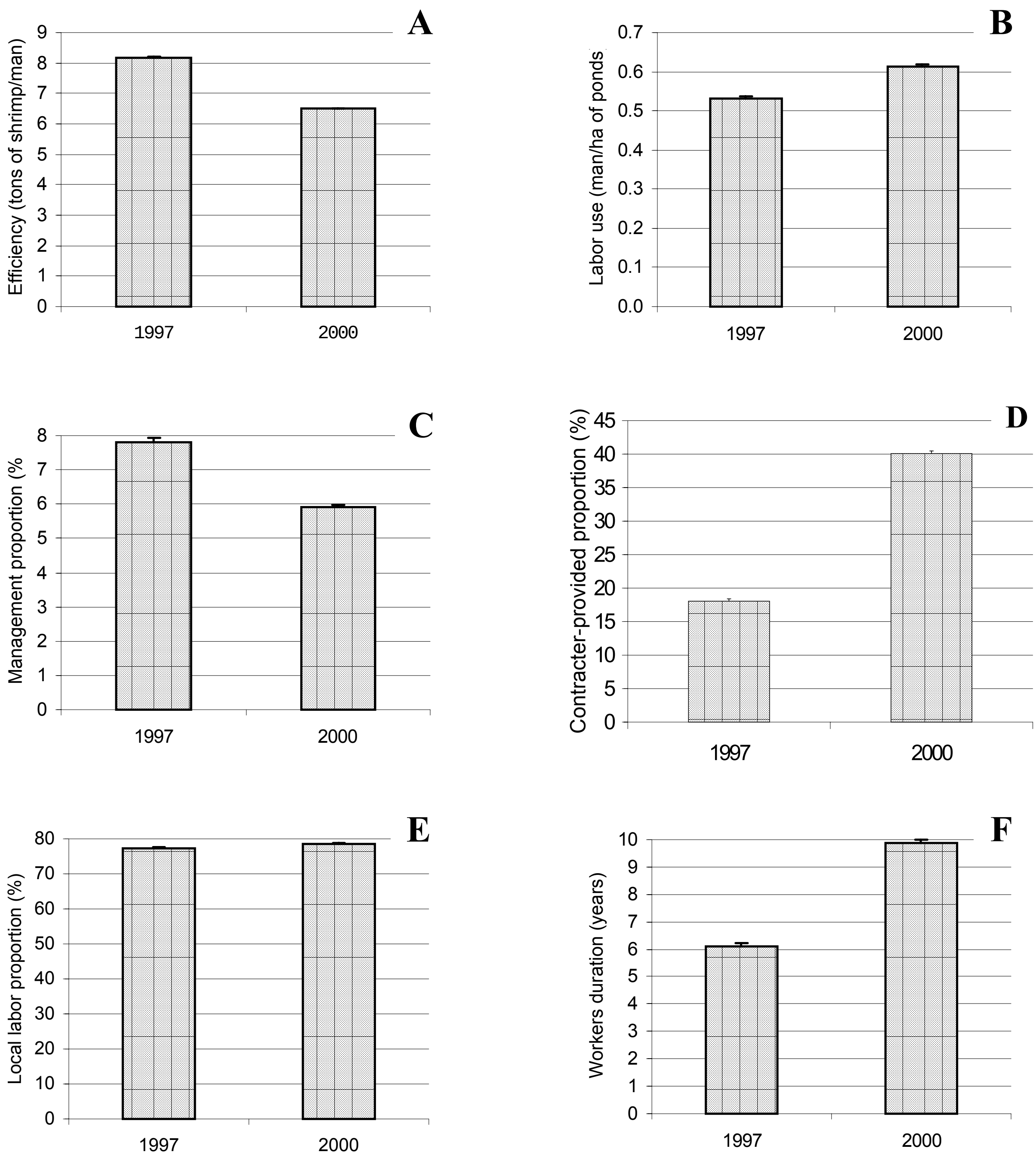


Figure 8. Comparison of employment characteristics in 1997 and 2000 at shrimp farms along the Caribbean coast. Labor efficiency (annual shrimp production per labor unit) (A), intensity of labor use per productive unit (B), proportion of total labor that was management (executives and administration) (C), proportion of total labor that was contractor-provided (D), proportion of total labor that was local people (E), and average duration of workers in the company (F).

Table 22. Characteristics of employment in the farms surveyed.

Farm	Number of employees				Duration	Local origin	Contractor-provided	Labor use	Productivity
	Management	Workers	Contractor-provided labor	Total labor	(years)	(%)	(%)	(men/ha)	(tons/year/man)
1	10	70	60	140	10	84.7	42.9	1.23	3.3
2	2	29	20	51	5	92.5	39.2	0.59	3.6
3	16	137	186	339	8	70.1	54.9	0.53	7.3
4	7	35	10	52	4	76.3	19.2	0.37	7.5
5	14	140	50	204	10	70.6	24.5	0.52	7.3
6	15	132	80	227	15	91.7	35.2	0.85	5.2
Total	64	543	406	1013					
Weighted mean					9.9	78.5	40.1	0.61	6.5
Standard Error					0.1	0.3	0.4	0.01	0.0

Employees of all farms are provided benefits in addition to salaries, including access to health care provided by the public social security service, paid vacations, and participation in a retirement program. All surveyed farms also provide some additional benefits to their employees. Loans, saving funds, educational opportunities, subsidies, bonuses, medical consulting, and housing assistance were cited by the managers interviewed, but benefits vary depending on the company.

Four farms also have social programs in the villages where their employees live. Four fronts of action address the same priorities in most villages: health care, education, housing, and public services. All four companies employ a health care worker to promote health programs with local populations. They also provide funds to healthcare clinics to buy materials and medicines. Two companies organize visits with physicians employed by them. Three companies help schools financially, to maintain and improve the facility and to buy materials, and two companies even employ a total of 13 teachers in several schools. One company also organizes ecology education sessions for young students. Some farms help people improving houses by providing building materials. But all four farms also focus on projects that benefit the whole community. They help maintain roads, bridges, channels, and public buildings. They finance playgrounds, classrooms, restrooms, aqueducts, and bridges. One company also supports projects such as an agricultural cooperative, and horticulture and freshwater aquaculture units. Finally, all farms organize social events, such as sports competitions, barbecues, and other kinds of feasts, to integrate the farm into the community's life.

Economic Aspects

Managers indicated production costs in grow-out farms of US$2–4 per kg of shrimp produced. Some such estimates do not necessarily include all the costs involved, such as financial or administrative costs that could be partially covered by other divisions within a company. An average cost of US$3 per kg seems to be fairly accurate. The manager of a company that includes the whole production chain, from hatchery to processing plant, indicated that the total production cost is US$4.80 per kg. This does not include administrative, financial, and marketing costs. In all cases, production costs seem to have been reduced since 1995, when an estimate of US$4.40 per kg was given by Acuanal as an average for the whole industry (Table 23).

According to information provided by two managers, the net profit margin of grow-out farms fluctuates between 0 during the first cycle when lower growth coincides with lower market prices, and US$3 per kg sold during the second cycle, when better growth coincides with higher prices. The average annual margin may be around US$1 per kg sold. According to a manager, the largest margin was obtained in 1994, when prices were the highest. The very low margin obtained during the first months of the year is the main reason that some farmers prefer to produce only two cycles a year.

Cost distribution seems to be highly variable by company; see the data given by Acuanal (Table 23) and by two managers during the interviews (Table 24). It probably depends on the profile of each company and, most of all, on the level of integration of different activities within the same company. Nevertheless, some general tendencies can be pointed out. Feeds and fertilizers are the main expense in growing shrimp, and post-larvae cost is almost as high as this nutrient cost. Labor costs seem to have grown in importance, while financial costs seem to have decreased in the last 5 years, perhaps a sign of a more mature industry.

Now that PL are produced locally, farms depend on importation only for shrimp feeds and soybean meal. Fertilizers used in farms are all produced in Colombia, except soybean meal imported from the USA. Diesel fuel is produced domestically from oil extracted in Colombia. About 60% of the feeds used in the farms surveyed are produced in Colombia. Most farms use several feed providers; Purina-Colombia is the primary one, and Italcol is the other Colombian brand cited by managers. One farm makes its own feed and uses it in addition to other brands. Forty percent of the feeds are imported, mainly from Peru

(Nicovita) and also from the USA (Ziegler). Even in the case of feeds manufactured in Colombia, most ingredients included in shrimp diets (fishmeal, shrimp meal, soybean meal) are imported.

Annual gross income of the six producers ranged from US$1.5 million for a company that includes just a single middle-sized farm and sells its product to a local processing plant, to US$23 million for the company owning the largest pond area and the country's main processing plant for cultured shrimp. The four biggest shrimp farms (including this one with a processing plant) export their product under their own names. The other two farms surveyed and all other small farms located on the Caribbean coast of Colombia sell their product either to the two companies that own processing plants (surveyed in this study), or to other processing plants specializing in fisheries products (Table 3).

Table 23. Distribution of production costs in Colombian shrimp farms in 1995

	Cost per kg of shrimp produced	
	(US$)	(%)
Post-larvae	0.82	18.6
Feeds	0.71	16.1
Fertilizers	0.05	1.1
Labor	0.35	8.0
Materials and other supplies	0.19	4.3
Maintenance	0.06	1.4
Transport and other services	0.19	4.4
Administration	0.48	10.9
Subtotal direct costs	2.85	64.7
Indirect costs	0.68	15.3
Financing costs	0.88	20.0
Total	4.41	100.0

Source: Acuanal.

Table 24. Distribution of production costs (percentages) in two Colombian shrimp farms in 2000

	Farm 1	Farm 2
Post-larvae	30	15
Feeds	35	20
Fertilizers	10	5
Labor	12	25
Diesel, maintenance, and services	-	20
Financing costs	-	15
Total	87	100

Source: The farms' managers.

Processing Plants

All processing plants listed in Table 3 are located in Cartagena (more than 400,000 inhabitants), in the same industrial area (Mamonal, or free, zone). This industrial zone extends along the Bay of Cartagena, a semiclosed natural lagoon. The lagoon hosted a coral reef ecosystem in the past, but the ecosystem was destroyed by pollution from sediments, organic matter, and chemicals. This pollution originated in the continuous discharge of terrestrial waters from the channel dug by the Spanish (Canal Del Dique) for aquatic transportation of goods, and the discharge of untreated domestic wastewater and industrial wastewater (including from an oil refinery).

Several processing plants were already established when shrimp farming started in the 1980s. Those plants process mainly tuna and shrimp from fisheries. Shrimp farmers first relied on those plants to process their product. Now that the two biggest shrimp farming companies each operate their own processing plant, only a small proportion of cultured shrimp is still processed in the long-standing plants.

Production and Resource Use

The two processing plants surveyed process about 90% (estimated) of the shrimp produced in Caribbean farms. They process an average of 38 tons per day (Table 25). Both plants also process wild shrimp representing 4.4% of their production. The majority of the shrimp that each plant processes is raised in the farm owned by the same company. They also process shrimp cultured in other farms, either buying the shrimp and marketing it under their own name, or charging the processing costs to the farms that wish to market their product on their own.

Both plants produce head-on shrimp as a large majority of their total product. One plant cooks 25% of its head-on shrimp. Therefore, the cooked product represents 22.5% of the total production of the plant. In the other plant, 17% of the tails are peeled (Table 25).

Both plants consume about the same volume of water (Table 26), but the plant that cooks some shrimp consumes 6.5 m^3/ton of shrimp, against 4.8 m^3/ton for the other plant. Water use of 10 and 3 m^3/ton, respectively, were reported by these plants in 1997. Water is used mainly to clean shrimp and to wash the facility and equipment. Other uses include making ice (neeeded for transporting shrimp from farms to the processing plants), and meeting the workers' needs (restrooms, cafeteria).

Chemicals used in processing plants are mainly chlorine and sodium metabisulfite. Tego 51 (from Merck®) was the only other chemical cited by plant managers. It is a bactericide used for cleaning hands and sensitive products, such as peeled tails. Chlorine is eventually added to water supplied by the public water works in amounts calculated to maintain a concentration of residual chlorine of 1.5-2 mg/L. Chlorine is also used to disinfect all sorts of surfaces, equipment, and materials used in processing. The plant that cooks shrimp consumes twice as much chlorine per ton of shrimp processed as the other plant (Table 26).

Sodium metabisulfite (SO_2) is applied to shrimp in prolonged baths, in a 5% solution. Sodium metabisulfite is an antioxidant that prevents any discoloration of the product. Colombian producers declare not liking to apply this product since it is irritating and could negatively affect workers' health. But they also report that it is required for head-on shrimp by their purchasing clients. The plant that produces only uncooked shrimp aims for a maximum concentration of 100 ppm of SO_2 in muscle, while the other plant has an objective of 70–80 and 40–70 ppm of SO_2 in muscle for shrimp exported to Europe and the USA, respectively. As a result, the first plant consumes 76% more SO_2 per ton of shrimp processed than the other plant (Table 26). Nevertheless, the minimum amount of sodium metabisulfite that is an effective antioxidant has been recalculated recently. Use of this chemical per ton of shrimp processed was thus reduced by more than 60% from values reported in 1997.

Waste Generation and Management

Both plants produce solid waste equivalent to 9–10% of the weight of shrimp processed (Table 26). Those wastes consist of shrimp heads and exoskeletons; shrimp too small to be sold; and small fish, crustaceans, and other detritus from harvested ponds. One plant gives its solid wastes (free) to crocodile farmers that use them in self-made feeds. The other plant sells part of their wastes to the same crocodile farmers for a price of 60 Colombian pesos per kg (US$30 per ton). The same plant also sells solid wastes to a chicken feed manufacturer for 120 Colombian pesos per kg (it must store wastes in ice in that case).

The amount of liquid waste is equivalent to 75–80% of the volume of water consumed (Table 26). The remainder (20–25% of the total consumption) is basically used for making ice. Since water is used for washing the products as well as the facility, liquid wastes usually contain a fair amount of fine solids, organic detritus, and chemical residues.

Table 25. Production characteristics of the processing plants surveyed

Processor	Construction	Expansion	Capacity (tons/day)	Production (tons/day)	Source of the product (%)		Product qualities (%)			
					Cultured	Wild	Head-on	Head-off	Peeled tails	Cooked
1	1983	1990	25	22	96	4	74	26	4.4	0
2	1989	1996	16	16	95	5	90	10	0	22.5
Weighted mean				19.5	95.6	4.4	80.7	19.3	2.6	9.5
Standard error				0.5	0.1	0.1	1.3	1.3	0.4	1.8

Table 26. Input consumption and waste generation of the processing plants surveyed

Processor	Water consumption		Chlorine consumption		SO_2 consumption		Solid waste		Liquid waste	
	(m^3/day)	(m^3/ton)	(kg/year)	(kg/ton)	(tons/year)	(kg/ton)	(ton/day)	(%)	(m^3/day)	(%)
1	106	4.8	1250	0.22	48	8.3	2.0	9.1	80	75
2	104	6.5	1900	0.45	20	4.7	1.6	10.0	83	80
Weighted mean	105.2	5.5	1524	0.31	36.2	6.8	1.8	9.5	81.3	77.4
Standard error	0.2	0.1	53	0.02	2.3	0.2	0.0	0.1	0.3	0.4

Table 27. Characteristics of employment in the processing plants surveyed

Processor	Number of employees				Duration	Contractor-provided labor	Local employment	Productivity
	Management	Workers	Contractor-provdied labor	Total labor	(years)	(%)	(%)	(kg/day/man)
1	12	248	40	300	8	13.3	96.7	73.3
2	30	13	115	158	8	72.8	84.2	101.3
Weighted mean					8	33.8	92.4	83.0
Standard error					0	1.3	0.3	0.6

Both plants are equipped with screens over floor drains that allow the removal of coarser solids. One plant is located in an industrial-free zone that manages a water treatment plant for all users. Liquid wastes are pumped 500 m away to the treatment plant, which includes screens, aerobic reactors with activated sludge, sedimentation tanks, solids traps, and a chlorinating tank. The other processing plant has its own treatment system. It includes solid and grease traps, an aerobic reactor with activated sludge, a sludge concentration tank, and a chlorinating tank. This improved system, recently implemented, has allowed TSS and BOD_5 in discharged water to be reduced by 99%, and as a result, the environmental tax is reduced, too. According to data provided by the latter plant, 6.8 kg of TSS and 157 kg of BOD_5 are now discharged monthly. Treated wastewater is discharged from both plants to the Bay of Cartagena. Domestic wastewater is collected in septic tanks.

According to Colombian law, wastewater treatment has to remove at least 80% of Total Suspended Solids (TSS) and Biochemical Oxygen Demand (BOD_5). The environmental authority also encourages a continuous improvement of removal efficiency by charging a tax (on TSS and BOD_5 loads) that increases regularly.

Quality Control and Biosecurity

Both processing plants have an HACCP plan approved by various agencies: the INVIMA (Instituto Nacional de Vigilancia de Medicamentos y Alimentos) for Colombia, the FDA for the USA, and the SGS for the European Community. HACCP plans include measures to prevent contamination of the product with pesticides or mercury and to control the antibiotic content of the products; the presence of pathogens in water, ice, and products; and the SO_2 concentration in products. Both plants have also developed written procedures for production, waste management, quality control, hygiene, and disease prevention. Both plants are also involved in environmental management plans developed locally with industry organizations (tax free zone, Fundación Mamonal). These organizations worked with the environmental authority to develop better management practices aimed at improving the ecological and social conditions of the area. Those plans include environment assessment and remediation; landscape improvement; educational programs; production technologies; waste minimization, treatment, and recycling; financial incentives; and administrative procedures.

Table 28. Quality control measurses for products and elements in contact with products (water, ice, building surfaces) from processing plants

Measure	Number of plants reporting
Mesophile aerobes	2
Total coliform	2
Fecal coliform	2
Staphylococcus	2
Aureus coagulosa	1
Salmonella	1
Vibrio cholerae	2
Pseudomonas spp	1
Pseudomonas aeuroginosa	1
Sulfite reducers	1
Fungus	1
Sulfite	2
Antibiotic residues	1
Pesticides	1
Mercury	1
Chlorine	2
pH	2
Temperature	1

Table 29. Parameters monitored in wastewater discharged by processing plants

Parameter	Number of plants reporting
Temperature	1
Dissolved oxygen	1
pH	2
Conductivity	2
Total nitrogen	1
Total phosphorus	2
Ammonia	2
Nitrate	2
Nitrite	2
BOD_5	2
COD	2
Total suspended solids	2
Settleable solids	2
Oils and grease	2
Total coliform	2
Fecal coliform	2

Each plant is equipped with a quality control laboratory. Parameters monitored to control quality during processing are listed in Table 28. Frequency of measurements varies from once a day for measures applying directly to the product or chlorine residue in water, to once a week for microbiological quality of water and ice, or once every two weeks for microbiological check-up of building surfaces. Quality control laboratories are also equipped to monitor the quality of wastewater. The environmental authority requires a monitoring of wastewater quality on a quarterly basis. Parameters monitored are listed in Table 29. One plant performs the same analyses monthly (and even daily for total and fecal coliforms) for better monitoring of water treatment efficiency.

Since processing plants receive shrimp from several farms and send ice chests to those farms for transportation of harvested shrimp, they occupy a key position in the chain of pathogen spreading. Ice chests and baskets used in shrimp transportation are assigned to a specific farm and never go to another facility. Every chest coming from a farm is washed and chlorinated. The same operation is repeated before sending ice chests to the farms. As already mentioned, water used to make ice is chlorinated. Finally, one processing plant is equipped with a chlorine bath allowing the disinfection of truck wheels at the entrance.

Employment and Personnel Management

The processing plants employ a total of 458 persons (Table 27), an increase of 9% over 1997. The average duration of personnel with the company increased from 5 to 8 years between 1997 and 2000. The two processing plants surveyed have a very different strategy for hiring workers. External contractors provide only 13% of the total employees in one case, against 73% in the other case. In both cases, the importance of contractors has increased since 1997. Workers are hired from the local population, which was the source for 92% of the employees in both plants. Labor productivity is 38% higher in the plant that produces the higher proportion of head-on shrimp; deheading shrimp and producing peeled tails requires more labor time (Table 27). Worker efficiency in this last plant improved since 1997, however. In contrast, worker efficiency decreased in the other plant, probably because of the development of the cooking component.

Health problems related to working conditions reported by the manager of one plant include respiratory difficulty that can result from contact with sodium metabisulfite, and hands and feet problems related to the constant high humidity. Both managers reported managing health issues by providing appropriate body protection (coats, boots, gloves, masks) and personnel rotation. Both plants have a written plan of procedures to prevent injuries and human diseases. The personnel of both plants can be treated (for free and on a permanent basis) by a nurse or a physician employed by the company, for any kind of health problem.

Besides benefits (including access to publicly provided health care, paid vacation time, and participation in a retirement program, employees of both processing plants surveyed are provided additional benefits. Companies provide free transportation from neighborhoods to the plant. Other benefits that may vary from one company to the other include bonuses, food subsidies, educational opportunities, loans, and saving programs.

Economic Aspects

Only 1–2% of cultured shrimp produced in Colombia are sold on the national market. The rest of the production is exported, mainly to Europe and the USA. Head-on shrimp are sold on the European market, mainly in Spain and France. Unpeeled head-off shrimp are exported to the USA. Peeled tails are sold mainly in Japan and secondarily in Europe. The two processing companies surveyed market their own products. Prices are negotiated with clients on the basis of the "green list." One manager reported selling shrimp for an average price of US$7–8 per kg. If this farm bought shrimp from farms owned by other companies, it would pay a price of US$6.30/kg for the most common size (60/70). The plant that processes only uncooked products reported exports of US$22.3 million annually, with a profit margin of US$2 million. The margin is equal to US$1.00/kg for head-on shrimp and US$0.85/kg for head-off shrimp. The manager of the other plant reported an average cost of processing of US$1.35/kg. Acuanal reported in 1995 that the average processing cost for all the such facilities in the country was US$0.88/kg. One manager mentioned that when they process shrimp from other companies, they prefer to buy the product and resell it, instead of just charging for processing costs, because the last activity is not profitable.

Discussion

The recent history of the Colombian shrimp industry was marked by two major events: the Taura Syndrome Virus outbreak and the development of a local stock that is resistant to TSV and free of WSSV. Both events are related to the issue of introducing foreign animals, and its implications will be discussed. We will analyze the effect of the new strategy, which consists of relying on local broodstock only, and on innovative management and production techniques and local employment - all focused on ensuring profitability.

Introduction of Shrimp from Other Countries

The main concerns about introducing foreign animals (new species) stem from their possible impact on the ecosystem and native species, and the introduction of diseases and their effects on both cultured animals and wild stocks (Pillay 1992). *Litopenaeus vannamei* and *L. stylirostris* are naturally present on the Colombian Pacific coast, but they were introduced to the Colombian Caribbean coast to develop a shrimp industry in the early 1980s.

Studies of the behavior of those foreign species in the presence of the native species *P. schmitti, P. notialis,* and *P. subtilis* were performed by INDERENA (the government agency in charge of aquaculture at that time, now named INPA) in the early 1980s. The conclusion was that these foreign species would have no negative impact on the native species. Thus, the introduction of both *L. vannamei* and *L. stylirostris* to the Caribbean coast was officially authorized.

Since then, no study has been conducted to assess the possible development of populations of *L. vannamei* or *L. stylirostris* in Caribbean coastal waters. However, managers admit that individuals sometimes escape from farms. All precautions are taken during the culture period, but escapes probably occur during harvest because it requires draining the ponds. Nevertheless, there is no report of the presence of those species by shrimp fishermen. Considering the importance of shrimp fisheries, all managers interviewed think that if *L. vannamei* or *L. stylirostris* had developed on the Caribbean coast, they would have been reported already.

Very little is known about the possible genetic impact of exotic species on native species. However, it has been demonstrated that interspecies hybridization among Penaeid shrimp is possible, at least across species belonging to the same subgenus (Benzie et al. 1995). The risk of introducing diseases into the environment also exists, and a study conducted by Ceniacua showed that *P. schmitti,* for example, is sensitive to TSV. The negative impact of introduced diseases, such as the Taura Syndrome, on the shrimp farming industry is unfortunately also well known.

Because of this last fact, relying on a local stock was an absolute priority for the Colombian shrimp industry. Within less than 2 years (between 1997 and 1999), producers located on the Caribbean coast increased their production of PL enough to meet from 25% of their needs to more than required to stock all ponds in operation. Thus, they even started exporting PL. This exceptional development was possible because hatcheries already existed but were closed or operating below their capacity because of initial production problems. Producers had only to reactivate their facilities and get them back to their production capacity. Only one new hatchery was created during this period. Farmers of the Caribbean coast reached their goal just in time to avoid the introduction of WSSV that spread over most Central and South American countries. On the other hand, Colombian farmers located on the Pacific coast did not have the capacity to develop a hatchery program so quickly, so they continued to import PL to meet their needs. Consequently, they were hit by White Spot Disease.

Since then, shrimp farmers persuaded the Colombian government to enact legislation to strictly reinforcing control movement of animals to protect against risky imports or transfers from one coast to another. Their current effort focuses on developing a local strain on the Pacific coast that has some resistance to the White Spot Disease; once it is developed, they can start increasing production using exclusively locally produced PL.

Comparing the recent events on the Pacific and Caribbean coasts of Colombia makes clear that developing and producing local stock is a key element in improving the sustainability of the shrimp farming industry.

Health Management and Biosecurity

Colombian farmers of the Caribbean coast successfully became self-sufficient in PL supply, and the domestication of a local strain is under way. This local strain is characterized by having some resistance to virulent pathogens already present on the Caribbean coast of Colombia, such as TSV, NHP, or IHHNV, and by being free of other viruses, in particular WSSV and YHV. They now possess a form of High Health Shrimp® stock (Pruder 1994) that can be called TSV-SPR/WSSV-SPF (Bédier et al. 1998; Fast and Menasveta 2000) in reference to the most devastating viruses in the Americas. Experience has shown that SPF stocks have a good potential for growth, while SPR stocks exhibit good resistance to certain pathogens (Bédier et al. 1998). But SPF shrimp perform well only in strictly SPF environments (Fast and Menasveta 2000); this kind of stock could be dramatically affected if exposed to new pathogens. Thus the current goal of Colombian producers is to protect their stock, especially by maintaining an environment free of new pathogens. No therapeutic measures are available for virulent pathogens such as viruses, intracellular bacteria, and intracellular parasites, so prevention is the only way to control them (Flegel

1998). Prevention is in any case the most efficient and economical way to avoid disease (Wang et al. 1999).

Farmers grasped the importance of controlling imports when farms were hit by Taura Syndrome. Acuanal played a key role, requiring members to commit to avoiding all animal imports. The appearance of the White Spot Disease on the Colombian Pacific coast reinforced the urgency for Caribbean coast farmers. Acuanal obtained additional enforcement measures for the law controlling imports of animals.

Once a domestic reproduction program is initiated, it must be accompanied by the construction of biosecure facilities to ensure a steady supply of High Health® or SPF (Specific Pathogen-Free) broodstock (Flegel 1998). Ceniacua initiated the process of closing the reproductive cycle in their facility and making it totally biosecure using recirculating technology (Samocha et al. 1999; Fast and Menasveta 2000). The construction of a second biosecure breeding facility on the Caribbean coast is planned.

Farmers' biosecurity plan also includes preventive measures to avoid spreading pathogens among facilities. Preventive measures are a series of special management procedures that require the understanding, agreement, and commitment of all producers and their staffs, primarily disinfecting equipment and materials, and destroying diseased animals. The process of developing these plans was led by Acuanal and Ceniacua.

Another aspect of the biosecurity plan is screening a large number of samples for the early detection of diseases. Two laboratories are in charge of this work on the Caribbean coast: Ceniacua and C.I. Oceanos. Ceniacua has spent an estimated US$500,000 since 1995 to set up two laboratories (in Cartagena on the Caribbean coast and in Tumaco on the Pacific coast) that include physics and chemistry, microbiology, histology, and PCR tests, with public funds obtained through research and technology projects. C.I. Oceanos, the biggest Colombian shrimp company, set up a similar laboratory in Cartagena with its own money. Staffs are well trained, and internationally recognized pathologists are regularly invited to participate. Equipment and methods used are up to date (Lightner and Redman 1998; Lightner 1999). PCR check-ups and health certificates are now general requirements for any transport of animals.

Another component of health management consists of providing a healthy pond environment (Flegel 1998; Lightner and Redman 1998; Wang et al. 1999). Since pond management practices have strong implications for production, decisions are made by each farm's staff individually; Ceniacua has not emitted any guidelines.

Defining adequate management practices is a complicated task since it is hard to set specific limits for a healthy pond environment. Nevertheless, as a general rule, avoiding stressful conditions will minimize the chance of infections by opportunistic pathogens (Plumb 1999; Wang et al. 1999). Good management methods applied in Colombia include the use of screens at the entrance and exits to ponds, water quality monitoring, strict control of feed rates, and health surveillance. Moreover, several additional improvements in pond management have been noticed since 1997. Stocking density was reduced by 35% on average, the number of cycles per year decreased and consequently drying time between crops has increased, disinfecting of soils is now commonly done (Table 14), and chicken manure is used less. Other preventive procedures implemented in other countries for combatting the White Spot Disease (Boyd 1999b) are being adopted by Colombian farmers. Still, more efforts are needed to define disease management protocols, in particular regarding removal and disposal of dead animals, water disinfecting, and sludge treatment (Wang et al. 1999).

Use of Drugs and Chemicals

Changes in management procedures (development of a local strain and the farmers' biosecurity plan) have led to important changes in drug and chemical use during the last few years. Most of the drugs and chemicals implicated in health management, as well as others commonly used, have implications for both the environment and food safety.

Antibiotics, used to treat vibriosis, are the therapeutants most commonly used in Colombia. In 1997, antibiotics were used commonly in hatcheries and nurseries, and sometimes in a few farms. Taura Syndrome was accompanied by infections by *Vibrios*, opportunistic pathogens (Flegel 1998). At that time, a few hatchery managers admitted using antibiotics as a preventive measure. Such prophylactic use of antibiotics is dangerous because it generates resistance within bacterial populations, including species pathogenic to both shrimp and humans (Brown 1989; Sze 2000). As a matter of fact, most managers interviewed have observed an increased resistance of bacteria to antibiotics. Most managers reported that oxytetracycline, the most commonly used antibiotic, is often ineffective; this finding has been reported in other regions (Macintosh and Phillips 1992). One manager even cited cases of antibiograms performed on imported PL that revealed bacteria that were resistant to all antibiotics available.

Vibriosis is still the main pathology experienced on the Caribbean coast of Colombia. Our survey showed increased awareness about risks associated with the use of antibiotics among managers, compared to 1997. It appeared that antibiotics are not used as a preventive measure anymore. Most managers interviewed declared that in case of bacterial disease, they perform antibiograms and determine the Minimum Inhibitory Concentration (MIC) to use before any application of antibiotic. Ceniacua played a key role in the development of diagnostic tests and procedures for proper use of antibiotics, and it performs microbiological tests for most producers.

Oxytetracycline is the most commonly used antibiotic; it is approved by the US Food and Drug Administration (FDA) for use in food fish (Plumb 1999). Furazolidone and chloramphenicol are also used by several hatcheries or nurseries (Table 9), though neither of them would ever be approved for use in food production because they are harmful to people (Williams and Lightner 1988; Brown 1989; Sze 2000). However, they are widely used in countries that do not have any regulation of drug use in aquaculture (Brown 1989; Macintosh and Phillips 1992). A problem would occur if residues were detected in the final product, which would cause its rejection by buyers (Macintosh and Phillips 1992; Reilly and Käferstein 1997; Sze 2000). Withdrawal times of antibiotics in shrimp are not well documented (Sze 2000). Studies conducted on oxytetracycline in shrimp have shown that withdrawal time could vary from 5 days to more than 15 days, depending on the concentration used (Corliss 1979; Mohney et al. 1997). Corliss recommended that oxytetracycline should be used at a dose of 5,000 mg/kg of feed for about 14 days, with a similar withdrawal time to comply with FDA's requirement of zero amounts in edible tissue. Unlike other food products for which maximum residue limits are defined, a limit of zero is applied to antibiotics in seafood (Sze 2000). Antibiotics in shrimp muscle are checked by Colombian processing plants, as part of HACCP plans. The presence of pesticides and mercury that could have contaminated farms from terrestrial waters (Reilly and Käferstein 1997) is also checked in processing plants.

Another problem with the use of oxytetracycline in ponds is that residues can be found in sediment for as long as 180 days (Hektoen et al. 1995). Not only can such residues negatively affect microbial populations in pond soils but this long-term exposure of natural bacterial populations to antibiotic residues would certainly lead to the development of resistant strains (Brown 1989, 46; Reilly and Käferstein 1997; Sze 2000).

No list of approved drugs for aquaculture products exists in Colombia, unlike in the USA (Williams and Lightner 1988; Plumb 1999). Basically, farmers can use anything that is commercially available, with no specific guidelines or restrictions. A code of conduct for the use of drugs should be developed by the shrimp industry. Implementing HACCP programs on farms is a difficult task, and the first step is making a commitment to use better management practices (Reilly and Käferstein 1997). Associations have a key role at this point in informing members and establishing guidelines and rules (Wang et al. 1999).

Our survey showed that the use of chlorine has been intensified, mostly in hatcheries and nurseries, as part of biosecurity procedures recently implemented. High concentrations are used; so discharged water could negatively affect life within the vicinity of the discharge structure. Chlorine degrades when exposed to sunlight, or it can be detoxified by treatment with sodium thiosulfate (Boyd 1996). In both cases, facilities should be equipped with a tank or pond to allow for chlorine residue dissipation before discharging treated water. Our survey showed that only two facilities (the same ones as in 1997) are equipped with such a system. The cost of constructing a 500-m² lined pond is roughly US$3,000, so cost is not an issue here. The reason is probably that managers do not believe that chlorine is very harmful to the environment. However, if we consider biosecurity issues, a receptor tank would also be a good safety device in case of disease; it could be used to avoid any introduction of pathogens into the environment.

Sodium metabisulfite, used in farms to treat harvested shrimp, is also naturally degraded in water and therefore does not have any long-term effect on the environment. However, it is a very powerful reducing agent that would drastically deplete dissolved oxygen near the outflow point. Again, a simple receptor pond equipped with an aeration device would be a good safety measure to avoid any negative environmental impact. However, none of the farms surveyed is equipped with such a facility.

The other issue associated with sodium metabisulfite concerns human health, especially in processing plants. Sodium metabisulfite is very irritating to the respiratory organs. Processing plants have adopted precautionary procedures for their personnel. But Colombian farmers do not have alternatives here, since using sodium metabisulfite is dictated by their clients. Sulfite concentration in the product is also carefully controlled by HACCP plans. The use of sodium metabisulfite for shrimp processing needs to be addressed at a global scale in coordination with government agencies and marketers.

All farms surveyed use a large quantity of fertilizers. The amount used per ton of shrimp was about the same in 1997 and 2000 (Figure 7), but we observed a switch from organic fertilizers to inorganic fertilizers (Figure 7). This is a positive change in the sense that the use of manure (chicken manure is the organic fertilizer most commonly used) in aquaculture ponds is questionable (Boyd and Massaut 1999). Nevertheless, certain inorganic fertilizers present some risks to human and environmental safety (Boyd and Massaut 1999). Even if Colombian farmers use inorganic fertilizers in a sound manner (doses are applied to give a final concentration of nitrogen and phosphorus lower than 1 mg/l), there is still a risk of contamination and eutrophication of both ponds and the receiving water body. As a matter of fact, Gautier et al. (1998) observed a higher discharge of inorganic nutrients in Colombian ponds receiving systematic weekly doses of fertilizers than in those that were fertilized less frequently.

Farms also use a large quantity of fuels, mainly diesel for pumps. Fuels should be stored in a proper way, because otherwise they could create environmental and safety hazards (Boyd and Massaut 1999). All farms store fuels in high-quality tanks installed above the ground, and improvements in storage conditions were noted (since 1997). Most farms built containment basins around fuel tanks to avoid spills.

Most chemicals used in farms present some risk for human safety, especially for the personnel that handle them (Boyd and Massaut 1999). Chemicals such as fertilizers, chlorine, and sodium metabisulfite—or other hazardous products, such as paints and lubricants—are all stored in closed concrete buildings. Also, most farms designated all hazard sites. Trash containers were placed around most farms, and detritus is sorted and either destroyed, recycled, or disposed of in a landfill, depending on the material. A significant improvement has been noticed between 1997 and 2000 in the way hazardous sites are designated and protected, and wastes are collected and treated in farms, probably related to the implementation of HACCP protocols in processing plants and the resulting consciousness of managers about risks.

Production Efficiency

Without any doubt, the main achievement obtained by Colombian farmers between 1997 and 2000 was the reopening of all closed hatcheries, nurseries, and farms located on the Caribbean coast. A new hatchery was also created, and most nurseries are expanding. Most farms are also expanding, and a project exists to construct a new one. The development of a TSV-SPR/WSSV-SPF stock has also contributed to the final result of increasing production (Figure 2) and exports (Figure 1). The Colombian domestication program includes two aspects: a genetic selection program led by Ceniacua and a mass breeding program conducted by producers. Advances in the first program are progressively transferred into the second by providing genetically improved animals.

Lower incidence of diseases has allowed for higher survival, another contributor to better production by nurseries and farms in 2000. The current survival rate at farms (65% on average) is about twice that in 1996 (Figure 4), when farms were most affected by the Taura Syndrome. Consequently, farms have cut back on stocking density to avoid overwhelming the carrying capacity of their ponds. The average maximum stocking density reported in this study is 28 PL/m², and the overall average has decreased by 30% from 1997 to 2000.

The use of domesticated broodstock presents some advantages for production, from the reliability of supply, better production scheduling, and lower cost when compared to wild broodstock (Preston et al. 1999). Additional benefits in using domesticated high health broodstock include enhanced growth and survival rates (Gjedrem and Fimland 1995; Gjedrem 1997; Preston et al. 1999). As a result, profitability and sustainability are expected to improve. Benefits can be optimized by combining high health stock and selective breeding (Gjedrem and Fimland 1995). Genetic gain can be rapid in shrimp because of their high fecundity, short generation time, and, at least for growth, the additive effect of genetic variance. A selection program can be expected to produce a gain in growth of 10–20% per generation, or per year in the case of shrimp (Gjedrem and Fimland 1995; Gjedrem 1997).

Suarez et al. (1999) reported a heritability rate—the proportion of the observed phenotypic variation that might reasonably be attributed to genetic causes (Fredeen 1983)—of 0.40 on the growth trait for the first generation issued from their family selection program (52 families), better than such rates reported for other species (Gjedrem 1983). However, the most spectacular benefit obtained by Colombian farmers with the first generation was a 29% improvement in survival (survival rate increased from 45.2% to 58.3% on average) (Suarez 1998). Suarez (Personal communication 2000) calculated that pond yield improved by 19% with the use of selected stock, compared to imported nauplii, mostly because of a higher survival rate. Suarez also calculated that pond productivity has increased from 5.4 kg/1,000 PL with imported nauplii to 7.1 kg/1,000 PL with selected stock. The heritability rate on survival was only 0.13, low when compared to other studies, but little has been reported on the heritability of pathogen susceptibility for shrimp selection programs (Bédier et al. 1998). Similar low heritability values have been reported in fish (Gjedrem 2000).

Another interesting trend is the decrease in the average number of production cycles per year in farms between 1997 and 2000. Some farms now choose to not stock ponds between September and December, because yields are usually lower between November and April (the dry season) than during the rest of the year (Figure 5). This phenomenon is poorly understood. However, ponds harvested during the dry season are stocked during the period of most abundant rainfall. Thus, a possible explanation is that degraded water quality during the peak of the rainy season could have negative effects on post-larvae and juvenile growth during the first weeks of culture. Another hypothesis is a drop in natural productivity of coastal waters during the dry season because of the decrease in mangrove litter carried by terrestrial runoff (Larsson et al. 1994), which would reduce growth during the second part of the production cycle. A potential benefit of this practice (which dries the whole farm for a few months) is increased sustainability resulting from the oxidation of all organic wastes from previous production cycles and the elimination of pathogen carriers.

An important characteristic of the Colombian shrimp industry is the use of fertilizers to stimulate and control the development of planktonic and benthic flora and fauna. We observed a switch from organic fertilizers to inorganic fertilizers between 1997 and 2000. This can be interpreted as reflecting a better understanding of nutrient manipulation to control the phytoplankton community, consistent with the common recommendation that inorganic fertilizers are better than manures in large-scale aquaculture (Boyd and Tucker 1998). Colombian farmers still apply organic fertilizers, but they use mainly agricultural byproducts and animal feeds that have a low C:N ratio and are quickly decomposed. Thus, we can expect improved water quality in ponds from the change in fertilization practices. Nevertheless, intensified use of inorganic fertilizers can be responsible for increased discharge of inorganic nutrients through water exchange (Gautier et al. 1998).

On the other hand, Colombian farmers decreased the rate of water exchange from 12% of pond volume per day to 5% per day between 1997 and 2000. They responded to the conclusions of some studies that showed water exchange rates could be drastically reduced without negative impact on shrimp production (Hopkins et al. 1993; 1995). Reducing water exchange allows for a better recycling of nutrients in ponds and consequently less discharge into the environment. In that sense, Colombian farmers have responded to the increased criticism based on possible effects of shrimp pond effluents on the environment. As a result, we observed that Colombian farmers use less water per ton of shrimp produced, also consuming less diesel fuel and reducing production costs in the process.

Effluent Quality

Effluent volume and composition are major issues in shrimp farming because of the possible negative impact on receiving water bodies—the main risk is eutrophication. Shrimp pond effluents may be rich in nutrients, organic matter, and suspended solids, which come from uneaten feeds, fertilizers, feces, organisms, and suspended soil particles (Boyd and Tucker 1998). The Colombian environmental authority is implementing a new regulation on effluent quality based on differences in BOD_5 and TSS values measured at the entrance and the exit of facilities. Colombia is one of the first countries in the Americas to regulate aquaculture effluents. The approach of analyzing the differences between input and output water is unique; all other standards for aquaculture effluents use limit values (Boyd and Tucker 1998; Boyd and Gautier 2000).

In 1997, none of the facilities surveyed were monitoring effluent composition, and in 2000 this was still true of hatcheries and nurseries. Because they treat inlet water and maintain a low biomass in their facilities, managers assume that BOD_5 and TSS are lower in their effluent than in the input water (which come from the open sea in most cases). However, four farms out of six that were surveyed in this study now monitor BOD_5 and TSS in their effluent. Two farms also measure other parameters (Table 19). Preliminary results of effluent monitoring reported by two farms indicated that BOD_5 and TSS concentrations are within the range of normal variation for semi-intensive farms (Boyd and Gautier 2000), indicating no (or little) increase in either BOD_5 or TSS due to their activity. Thus, if any contamination tax is charged to these farms, it should be minimal. However, Gautier et al. (1998) observed increases in TSS in some Colombian farms as an effect of shrimp culture. As a matter of fact, two farms implemented systems to reduce suspended solids in their effluents. One farm built sediment traps in the discharge canals, and a second one built a long canal and a biofilter using a mangrove wetland. The first system is fairly simple and inexpensive, while the second one cost about US$100,000 (Gautier 2002). In conclusion, some farms may still have to implement better management of treatment systems to avoid the payment of any contamination tax, and it may have some cost. Pillay (1992) indicated that sedimentation followed by some sort of biological treatment is likely to be the most feasible means of aquaculture waste treatment.

Processing plants are already paying contamination taxes for their BOD_5 and TSS loads. One processing plant was equipped with a rather inefficient treatment system in 1997, and they were paying a contamination tax of US$300 per month on average. After spending US$29,500 to improve the treatment system, they have much cleaner effluent and now pay only 1% of their previous contamination tax.

Another issue with effluent quality stems from the use of chemicals (mainly chlorine and sodium metabisulfite) in large quantities in hatcheries, nurseries, and farms. As mentioned previously, detoxification of those compounds is not ensured in all facilities before their discharge into the environment. Both compounds are degraded through natural processes and their residues have no effect. Moreover, dilution of effluents by receiving water bodies would prevent any strong impact in most situations. Nevertheless, Colombian producers should improve on this aspect, and the solutions are not necessarily expensive (refer to the section above, The Use of Drugs and Chemicals).

Zoning, Land Occupation, and Mangrove Protection

Inadequate siting and bad design and construction are commonly identified as primary reasons for both environmental and social problems that result from shrimp aquaculture development in some countries (Phillips et al. 1993; Dierberg and Kiattisimkul 1996; Boyd and Clay 1998; Phillips 1998; Primavera 1998; Boyd and Schmittou 1999). No effective zoning regulation has been enacted for coastal development in Colombia. But human pressure on coastal lands is much less than in Asian or European countries. Nevertheless, INDERENA, the government agency in charge of aquaculture development at that time, identified some zones adequate for shrimp aquaculture development in the late 1970s and early 1980s. Availability of good water supply and undeveloped land was the main criteria taken in account. Some facilities were built in those areas, while others were built in different zones chosen by investors. A notable characteristic of the Colombian shrimp industry is that facilities were built on private lands. Thus, government had little opportunity to organize or influence the development of the industry.

Nevertheless, no serious problems related to farm concentration or conflicts over land and water use have been identified in Colombia. The only zone of high farm concentration is Covado Island near Cartagena, where four farms with 1,021 ha of ponds are already built and the construction of a fifth one is planned. Some risk of conflict and pollution exists in this area. Environmental Impact Assessments (EIAs) are powerful tools to improve the environmental sustainability of shrimp projects (Boyd 1997; Boyd and Schmittou 1999). The previous EIAs conducted by farms at start-up, about 15 years ago, failed to effectively evaluate the possible environmental impacts. This problem was then partially remedied by the requirement to develop environmental management plans. Nevertheless, better methodology is needed to conduct good EIAs for new projects.

The Colombian Ministry of the Environment has initiated studies of integrated coastal management and preservation of natural resources. Management plans have been proposed for mangrove ecosystems (Ulloa-Delgado et al. 1998). But there is no zoning regulation yet. Perhaps one of the most important challenges for both the Colombian government and the shrimp industry is to ensure sound development of coastal areas and sustainability of existing activities. Now that the shrimp industry is growing again after the difficulties experienced in the 1990s, it should work with the government to limit the risk of conflicts with other land and water users.

Nonsustainable projects have led to abandoned farms in some countries, contributing substantially to the bad image of shrimp farming (Phillips et al. 1993; Dierberg and Kiattisimkul 1996; Primavera 1998).

Disease outbreaks are the usual triggers that make shrimp companies go out of business. A similar situation was observed in Colombia between 1995 and 1997, when seven farms were closed because companies ran out of money due to high mortalities caused by the Taura Syndrome. Since then, all closed farms have been bought or rented by other companies. Only one small farm was converted into a community project. All other farms were reactivated and are now producing shrimp again. However, farm conversion remains an issue. Three farms out of six surveyed have a contingency plan. Alternatives to shrimp culture cited by managers include rice culture, salt production, and growing mangrove forests. Mangrove trees are very efficient colonizers, and it has been already demonstrated that just permitting free water circulation in ponds is enough to allow mangrove establishment (Lewis and Marshall 1998).

Another big issue discussed internationally is the impact of shrimp aquaculture on mangrove ecosystems, mainly mangrove destruction for building ponds (Phillips et al. 1993; Dierberg and Kiattisimkul 1996; Boyd 1997; Primavera 1998). Mangrove grows in estuarine areas on the Caribbean coast of Colombia, where some farms are located, however, no negative impact of shrimp farms on mangrove has been identified by a recent study by Sanchez-Paez et al. (1997). The reasons are several, starting with the geographical or technical. Tide magnitude is only about 30 cm on the Caribbean coast. Thus, farmers had to build ponds on higher lands in order to drain them properly. Therefore, all Colombian farms located in areas where mangrove coexists were actually built behind the fringe of mangrove. Farmers also claim they knew about the difficulty and prohibitive cost of building and managing ponds on mangrove lands that results from their physical and chemical properties.

Legislation also protects mangrove forest. Colombian laws prohibit any unauthorized mangrove cuttings. Basically, a "no net loss" rule has been applied in authorizing some cuttings in shrimp farms that needed to dig canals through mangrove. A total of 32.1 ha of mangrove has been cleared in the farms surveyed (Table 12). All farms involved were required to implement a compensatory planting program.

Nevertheless, construction of ponds and canals near mangrove ecosystems may have changed hydrological conditions in those areas. Hydrodynamics are an important variable in mangrove ecology (Chapman 1976). Studies of the impact of shrimp farm construction on mangrove ecology are still needed to guide future projects. The only known example of such studies is one analyzing an experimental mangrove wetland used as a biofilter to treat shrimp pond effluents (Gautier 2002).

Employment and Personnel Management

Coastal aquaculture is a tool that can alleviate poverty (Phillips 1998). However, shrimp farming has been more criticized for its negative social impacts on local populations than cited as a facilitator of economic and social development. Objections include land conversion, privatization and expropriation, increased food insecurity (through loss of mangrove and conversion or salinization of ricelands and freshwater aquaculture ponds), and marginalization and unemployment of affected populations (Bailey 1988; Primavera 1997, 1998).

None of those possible problems have been observed in Colombia, largely because of previous land use patterns. Shrimp farms in Colombia were built on unoccupied and unexploited lands. There is only one example of conversion of an extensive cattle ranch, which provided only a few jobs, into a shrimp farm. The reason is that population density is low, and most coastal lands are not highly productive. Another factor is that mangrove, wherever it existed, was not destroyed by shrimp farmers. In all cases, shrimp farms have provided additional job opportunities for local populations, who continued other traditional economic activities. Unemployment is a common problem in coastal Colombian communities. Employment opportunities provided by traditional activities such as fisheries or agriculture are not numerous enough to cover the needs of populations characterized by growth and youth (a majority are young people).

Employment opportunities provided by shrimp farms benefit most of all the local populations, who represent 78.5% of the total labor in the farms surveyed. Salaries and benefits provided by shrimp companies are better than those of most other rural activities. In most cases, additional benefits to those required by law are provided to employees. Most of the shrimp companies surveyed also help local communities by supporting programs of common interest such as health care, schools, and public infrastructure.

Bailey (1988) and Primavera (1997) also claimed that shrimp aquaculture is capital-intensive but not labor-intensive and therefore shrimp farming would not be a good alternative to traditional activities for providing benefits to local populations. The same authors reported that labor requirements for shrimp farming were only 0.1–0.2 people/ha, and 45 workdays/crop/ha (versus 76 workdays/crop/ha for rice culture). Our survey, in contrast, showed that labor use on the Caribbean coast of Colombia is 0.6 people/ha and 70 workdays/crop/ha on average. Thus, shrimp farming in Colombia appears to be a good alternative to rice culture, and certainly an excellent alternative to any form of extensive agriculture.

Temporary labor represents 40% and 34% of farm and processing plant employment, respectively. Those 2000 figures represent increases over 1997. It could be deduced that employment is becoming less stable in Colombian shrimp companies. Farmers learned to reduce labor to the minimum required when they experienced financial difficulties during the Taura syndrome event from 1995 to 1997. Afterward, they probably hesitated in restoring employment to previous levels. Farms are also reducing the number of cycles per year to eventually stop production for several months. This strategy reduces their need for permanent personnel and increases their need for temporary labor. However, contractors hire people from the same local populations as shrimp companies do. Moreover, farmers report that the personnel employed by contractors are as stable as the employees, mainly because the multitude of activities in shrimp farms ensure continuous employment to most people. Nevertheless, workers employed by contractors probably receive fewer benefits than shrimp company employees.

Economic Aspects

The development of a “high health” stock had important economic consequences for Colombian producers. The cost of nauplii was lowered by 33% when compared to the import price. Consequently, the price of PL also decreased by 22%. Producers have an agreed price for brooders, nauplii, and PL. The profit margin of nurseries remained about the same, around US$1.00/1,000 PL. However, nurseries benefited from the selection program because they improved production efficiency. Grow-out farms benefited even more from the selection program, since their production cost was lowered because they can stock ponds at a lower density, and they get PL at a lower price than in 1997. The average profit margin of farms is about US$1.00/kg, but managers reported that they do not make any profit from ponds harvested during the first months of the year. The margin of processing plants that are also exporters is also about US$1.00/kg.

Lower production costs are a direct result of the development of selected stock. It is too soon to do a detailed cost/benefit analysis, but we already have some indications. Acuanal received a US$1.8 million government grant to acquire the facilities required for starting a selection program. Such a program is very expensive, but the cost can be kept lower if the program focuses only on growth initially (Gjedrem and Fimland 1995). Ceniacua's selection program actually selects for two traits: growth rate and survival rate. Fortunately, a positive correlation was observed between these two traits (Suarez et al. 1999). Yearly cost for such a breeding program can be estimated in US$ 2.5–3 million (Gjedrem and Fimland 1995; Gjedrem 1997). But a very good return on investment of at least 10:1 can be expected, making a selection program extremely profitable in the end. No information on the overall costs and benefits of Ceniacua's selection program has been released yet, but Suarez (1998) calculated that the improvement in productivity obtained with the first generation of selected animals represented an increase in export value of 8.4% or US$ 2.5 million. Suarez (personal communication 2000) indicated that one farm reported an increase in profitability per ha of 80% with the use of selected stock.

In contrast to the independence from imports and the economic gain of Colombian producers on nauplii and PL supply, we observed an increased dependence on imports for both natural and artificial shrimp food. Fertilizers and 60% of the artificial feeds used in farms are produced in Colombia. However, most ingredients for these artificial inputs are imported. Most Colombian farmers use a 35% protein diet, whose price greatly depends on fishmeal's price. Imports of artemia cysts have become the second most important cost of nursery operations. Imported polychaetes are the main food of brooders in maturation facilities. The next economic challenge for Colombian farmers will be to ensure their supply of nutrients at a reasonable price. Alternative foods for brooders have to be indentified; for example, a local strain of *Artemia salina* could be exploitable. Strategies to take more advantage of natural productivity in ponds and reduce the use of animal protein in artificial pellets have to be developed.

Finally, addressing environmental challenges could also provide economic advantages. Environmental management plans are required by the environmental authority to obtain an operation permit. HACCP plans have also been required to allow processing plants to export their product. A vertically integrated shrimp company indicated that it budgeted US$60,000 and US$74,000 in 1998 to implement their environmental management plans in their processing plant and their main farm, respectively. Those budgets included investments, maintenance, studies/analyses, reforestation, and education. An outstanding question is how to make an environmental management system economically advantageous.

Conclusions

From the Colombian experience with Taura Syndrome, and also from other examples around the world (Chamberlain 1994; Qingyin et al. 1997), the relationship between disease outbreak and short-term sustainability of shrimp farming is quite obvious. Prevention is the only effective way to combat virulent pathogens such as viruses (Flegel 1998, Wang et al. 1999). Colombian shrimp producers learned the lesson quickly and then started the selection program that nowadays makes them so successful, while other regions are dramatically affected by White Spot Disease. (Note the contrast, however, with Venezuelan producers, who never experienced any dramatic disease outbreak thanks to their isolation strategy from the beginning of the shrimp industry there).

The Colombian example illustrates the different components of a biosecurity plan at a national level. Producers must commit themselves to a common effort to generate a local high health stock and stop importing animals. A further selection program to produce genetically improved stock is optional—but a good complement that can be highly profitable. Producers should also try to obtain appropriate legislation from their government to protect against damaging introductions of foreign animals. A significant effort has to be made to detect pathogens in culture systems, and measures to prevent pathogen circulation among facilities must be implemented. Common investments are needed to build totally biosecure facilities that require expensive recirculation technology. All these steps require coordination among producers. All achievements obtained by Colombian farmers so far were led by their association, Acuanal. The Colombian example also underlines the importance of associations in providing technical assistance and extension activities for the improvement of management practices in the industry.

The initial Colombian selection program for high health stock generated many benefits for participants. Producers obtain better survival rates and higher yields with selected local stock than with imported seed. Producers could further reduce the pressure on the environment by stocking at lower density, and reducing the months in production during the year. They have reduced water exchange rates in ponds and the use of fertilizers. Thus, they improved production while lowering costs *and* environmental impact. In sum, the Colombian domestication program made the local industry more profitable and more sustainable.

Shrimp farming in Colombia has a positive social impact on employees and communities surrounding farms. In most cases, shrimp farm construction did not mean any conversion of land use from other production. With the single exception, the shrimp farm employs as many or slightly more local people as other coastal activities. Traditional activities, such as rice culture, mangrove exploitation, or fisheries, were not affected because most of the farms were built on undeveloped lands and mangrove was not cleared. Shrimp farms simply provide new job opportunities to populations that usually experience high unemployment. Shrimp farms provide better salaries than any other traditional activity, even for unskilled jobs. Local communities also receive the support of shrimp companies, which supplement inadequate government-sponsored public services. Thus, shrimp farming is seen as providing good opportunity for economic and social development of the coastal populations in Colombia.

Still, the Colombian shrimp industry has other challenges to face. The reasons for limited yields during the dry season need to be elucidated in order to find management strategies that could make the activity profitable all year round. Alternative solutions to imports have to be developed to feed larvae, subadults and brooders. Improving environmental management of shrimp facilities and, more broadly, coastal areas to maintain good water quality is probably the most important and complicated goal to achieve on a long-term basis.

Environmental management plans are required by the environmental authority to obtain an operating permit. Significant achievements related to the implementation of those plans have been obtained between 1997 and 2000. Nevertheless, several environmental issues have not been addressed yet, and they may require more thorough and encompassing environmental management systems. In that sense, the implementation of the HACCP system has been very efficient in improving management in processing plants. Some Colombian companies are considering some form of environmental certification, such as ISO 14000, which would certainly help improve management of hatcheries, nurseries, and farms.

Most aquaculture activities remain unregulated, and Colombia is no exception. We observed that the enforcement of the regulation on effluent quality had a great effect on shrimp companies, which started monitoring effluent quality, reduced water exchange rates, and in some cases implemented treatment systems. In other cases, the shrimp industry wants to protect itself from possible negative impacts from the environment, as it is the case of the introduction of new pathogens. Those two examples illustrate the necessity for shrimp producers to work with the government to obtain needed protection from other activities, and to be treated fairly in regulations to control their own activity. In both cases, producers' associations have a key role in working with the government and in helping their members to comply with existing regulations and to prepare for complying with new ones.

Acknowledgments

This study is part of the program on shrimp farming and the environment funded by the World Wildlife Fund, NACA, FAO, and the World Bank. The author greatly thanks all the persons interviewed in Colombia for their time and collaborative spirit: Mr. José-Vicente Mogollón and Mrs. Verena Fuentes (Agrosoledad), Mr. Raul Remolina, Mr. Bernardo Herazo, Mrs. Ana-Verena Vargas and Mr. Nicolás Del Castillo (Océanos), Mr. Sergio Martinez and Mr. Augustin Uribe (Cartagenera de Acuacultura), Mr. Andres Suarez and Mr. Jorge-Arturo Suarez (Ceniacua), Mrs. Sara Velásquez (Proacuícola), Mr. Jorge Velez (Agromarina Santa Ana), Mr. Jonas Grigaliunas (Aquacultivos del Caribe), Mrs. Marta Torres (Rancho Chico), Mr. Edgard Arias and Mrs. María-Fernanda Virgüez (Hidrocultivos), Mr. Jorge-Hernán Restrepo (Idelcaribe). The author also thanks Mrs. Clara-María Sanín, president of Acuanal, for her collaboration in organizing the survey work. The author is also most grateful to Dr. Jason Clay and Dr. Claude Boyd for their support, comments, and suggestions.

References

Bailey, C. 1988. The social consequences of tropical shrimp mariculture development. *Ocean Shore Management 11*:31-44.

Bédier, E., J.C. Cochard, G. Le Moullac and J. Patrois. 1998. Selective breeding and pathology in penaeid shrimp culture: the genetic approach to pathogen resistance. *World Aquaculture. 29*:46-51.

Benzie, J.A.H., M. Kenway, E. Ballment, S. Frusher and L. Trott. 1995. Interspecific hybridization of the tiger prawns *Penaeus monodon* and *Penaeus esculentus*. *Aquaculture 133*:103-111.

Boyd, C.E. 1995. *Bottom Soils, Sediment, and Pond Aquaculture.* Chapman & Hall, New York, USA, 348 p.

Boyd, C.E. 1996. Chlorination and water quality in aquaculture ponds. *World Aquaculture 27*:41-45.

Boyd, C.E. 1997. Environmental issues in shrimp farming. In Alston D.E., Green B.W., Clifford III H.C. (eds), *Cultivo sostenible de camaron y tilapia. IV simposio centroamericano de acuicultura.* ANDAH, Puerto Rico. pp. 9-23.

Boyd, C.E. 1999a. *Codes of practice for responsible shrimp farming,* Global Aquaculture Alliance, St Louis, Missouri, 42 p.

Boyd, C.E. 1999b. Suggestions on pond management practices for combating White Spot virus. *V simposio Ecuatoriano de Acuacultura. Enfocando los retos del 2000*. 28-30 October 1999, Guayaquil, Guayaquil, Ecuador, pp. 1-6.

Boyd, C.E. and J.W. Clay. 1998. Shrimp aquaculture and the environment. *Scientific American 278*: 42-49.

Boyd, C.E. and D. Gautier. 2000. Effluent composition and water quality standards. *Global Aquaculture Advocate 3*:61-66.

Boyd, C.E. and L. Massaut. 1999. Risks associated with the use of chemicals in pond aquaculture. *Aquaculture Engineering 20*:113-132.

Boyd, C.E. and H.R. Schmittou. 1999. Achievement of sustainable aquaculture through environmental management. *Aquaculture Economic Management 3*: 59-69.

Boyd, C.E. and C.S. Tucker. 1998. *Pond Aquaculture Water Quality Management*. Kluwer Academic Publishers, Boston, USA. 700 p.

Brown, J.H. 1989. Antibiotics: their use and abuse in aquaculture. *World Aquaculture 20*:34-43.

Chamberlain, G.W. 1994. Taura syndrome and China collapse caused by new shrimp viruses. *World Aquaculture 25*:22-25.

Chapman, V.J. 1976. *Mangrove Vegetation*. J. Cramer, Vaduz, Florida, USA. 430 p.

Corliss, J.P. 1979. Accumulation and depletion of oxytetracycline in juvenile white shrimp (*Penaeus setiferus*). *Aquaculture 16*:1-6.

Currie, D. 1998. Colombian shrimp farmers prepare for the 21st century. *World Aquaculture 29*:18-21.

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

Echavarría, M., T. Huntington and D. Gautier. 1998. *Diagnóstico ambiental y plan de acción del sector camaronero colombiano*, Ecodecisión, MacAlister & Elliott, Quito, 114 p.

Fast, A.W. and P. Menasveta. 2000. Some recent issues and innovations in marine shrimp pond culture. *Review of Fisheries Science 8*:151-233.

Flegel, T.W. 1998. Shrimp health management and the environment. In Aquaculture Sustainability and the Environment. *Report on a regional study and workshop. ADB/NACA*, Bangkok, Thailand, pp. 286-293.

Fredeen, H. 1983. Monitoring genetic change. *Aquaculture 33*:1-26.

Gautier, D. 2002. *The Integration of Mangrove and Shrimp Farming: A Case Study on the Caribbean Coast of Colombia*. Report prepared under the World Bank, NACA, WWF and FAO Consortium Program on Shrimp Farming and the Environment. Work in Progress for Public Discussion. Published by the Consortium. 26 pages.

Gautier, D., J. Amador, L. Aragón, M. Bastidas, S. García, J.A. Pastrana, C. Ramos, W. Urango and F. Newmark. 1998. The effect of shrimp culture on nutrient and suspended matter concentrations in the Colombian Caribbean coast. *World Aquaculture '98, Book of Abstracts*. World Aquaculture Society, Baton Rouge, Louisiana, p. 198.

Gjedrem, T. 1983. Genetic variation in quantitative traits and selective breeding in fish and shellfish. *Aquaculture 33*:51-72.

Gjedrem, T. 1997. Selective breeding to improve aquaculture production. *World Aquaculture 28*:33-45.

Gjedrem, T. 2000. Genetic improvement of cold-water fish species. *Aquaculture Research 31*:25-33.

Gjedrem, T. and E. Fimland. 1995. Potential benefits from high health and genetically improved shrimp stocks. In Browdy C.L., Hopkins J.S. (eds), *Swimming Through Troubled Waters*. Proceedings of the special session on shrimp farming, Aquaculture '95. World Aquaculture Society, Baton Rouge, pp. 60-65.

Hektoen, H., J.A. Berge, V. Hormazabal and M. Yndestad. 1995. Persistence of antibacterial agents in marine sediments. *Aquaculture 133*:175-184.

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

Hopkins, J.S., P.A. Sandifer and C.L. Browdy. 1995. A review of water management regimes which abate the environmental impacts of shrimp farming. In Browdy C.L., Hopkins J.S. (eds), *Swimming*

Through Troubled Waters. Proceedings of the special session on shrimp farming, Aquaculture '95. World Aquaculture Society, Baton Rouge, Louisiana, USA, pp. 157-166.

INPA, 1997. *Boletín Estadístico Pesquero 1996*. INPA, Santafé de Bogotá. 107 p.

Larsson, J., C. Folke and N. Kautsky. 1994. Ecological limitations and appropriation of ecosystem support by shrimp farming in Colombia. *Environmental Management 18*:663-676.

Lewis, R.R. and M.J. Marshall. 1998. Principles of successful restoration of shrimp aquaculture ponds back to mangrove forests. *World Aquaculture '98, Book of Abstracts.* World Aquaculture Society, Baton Rouge, p. 327.

Lightner, D.V. 1999. The Penaeid shrimp viruses TSV, IHHNV, WSSV, and YHV: current status in the Americas, available diagnostic methods, and management strategies. *Journal of Applied Aquaculture 9*:27-52.

Lightner, D.V. and R.M. Redman. 1998. Shrimp diseases and current diagnostic methods. *Aquaculture 164*:201-220.

Lucien-Brun, L. 1997. Evolution of world shrimp production: fisheries and aquaculture. *World Aquaculture 28*:21-33.

Macintosh, D.J. and M.J. Phillips. 1992. Environmental issues in shrimp farming. In de Saram H., Singh T. (eds), *Shrimp '92 - Proceedings of the 3rd Global Conference on the Shrimp Industry.* Hong Kong, 14-16 September 1992, INFOFISH-EUROFISH. pp. 118-145.

Mohney, L.L., R.R. Williams, T.A. Bell and D.V. Lightner. 1997. Residues of oxytetracycline in cultured juvenile blue shrimp, *Penaeus stylirostris* (Crustacea: Decapod), fed medicated feed for 14 days. *Aquaculture 149*:193-202.

Newmark, F., A. Uribe, J. Amador and D. Gautier. 1997. Impacto del fenómeno "El Niño" sobre el cultivo de camarón en el Pacífico Colombiano. In Alston D.E., Green B.W., Clifford III H.C. (eds), *Cultivo Sostenible de Camarón y Tilapia. IV Simposio Centroamericano de Acuicultura.* ANDAH, Puerto Rico, pp. 171-174.

Phillips, M.J. 1998. Tropical mariculture and coastal environmental integrity. In De Silva S. (ed.), *Tropical Mariculture*. Academic Press, London, pp. 17-69.

Phillips, M.J., C.K. Lin and M.C.M. Beveridge. 1993. Shrimp culture and the environment: lessons from the world's most rapidly expanding warmwater aquaculture sector. In Pullin R.S.V., Rosenthal H., Maclean J.L. (eds), *Environment and Aquaculture in Developing Countries*. ICLARM Conference Proceedings 31. ICLARM, Bangkok, Thailand, pp. 171-197.

Pillay, T.V.R. 1992. *Aquaculture and the Environment.* John Wiley & sons, Inc., New York, 189 p.

Plumb, J.A. 1999. *Health Maintenance and Principal Microbial Diseases of Cultured Fishes.* Iowa State University, Ames, Iowa, 328 p.

Preston, N.P., D.C. Brennan and P.J. Crocos. 1999. Comparative costs of postlarval production from wild or domisticated Kuruma shrimp, *Penaeus japonicus* (Bate), broodstock. *Aquaculture Research 30*:191-197.

Primavera, J.H. 1997. Socio-economic impacts of shrimp culture. *Aquaculture Research 28*:815-827.

Primavera, J.H. 1998. Tropical shrimp farming and its sustainability. In De Silva S. (ed.), *Tropical Mariculture*. Academic Press, London, pp. 257-289.

Pruder, G.D. 1994. High health shrimp stocks: an advance, an opportunity - but not a panacea. *World Aquaculture 25*:26-28.

Qingyin, W., C. Shengli and L. Jian. 1997. The shrimp farming industry in China. *World Aquaculture 28*:23-29.

Reilly, A. and F. Kaferstein. 1997. Food safety hazards and the application of the principles of the hazard analysis and critical control point (HACCP) system for their control in aquaculture production. *Aquaculture Research 28*:735-752.

Samocha, T.M., L. Hamper, C.R. Emberson, A.D. Davis, A. Balafas, D. McIntosh, A.L. Lawrence, P.G. Lee and G.F. Wood. 1999. Potential Tools for Development of a Sustainable and Biosecured Shrimp Farming Industry. *V simposio Ecuatoriano de Acuacultura. Enfocando los retos del 2000*. 28-30 October 1999, Guayaquil, Guayaquil, Ecuador. 21 p.

Sanchez-Paez, H., R. Alvarez-Leon, F. Pinto-Nolla, A.S. Sanchez-Alferez, J.C. Pino-renjifo, I. Garcia-Hansen and M.T. Acosta-Penaloza. 1997. *Diagnóstico y Zonificación Preliminar de los Manglares del Caribe de Colombia*, Dirección General Forestal y de Vida Silvestre, Ministerio del Medio Ambiente, República de Colombia, Santafé de Bogotá, Colombia, 509 p.

Suarez, J.A. 1998. Antecedentes y perspectivas del programa de selección de una variedad "Colombia" del camarón *Penaeus vannamei*. In Jory D.E. (ed.), *Memorias del Primer Congreso Latinoamericano de Camaricultura.* Panama, 6-10 Octubre de 1998. 9 p.

Suarez, J.A., T. Gitterle, M.R. Angarita and M. Rye. 1999. Primeros resultados del programa de selección familiar del camarón marino *Litopenaeus vannamei*, realizado en Colombia. In Green B.W., Clifford III H.C., McNamara M., Montano G.M. (eds), *Acuacultura y Ambiente Juntos Hacia el Nuevo Milenio*. V simposio centroamericano de acuicultura. ANDAH, Choluteca, Honduras, pp. 82-84.

Sze, C.P. 2000. Antibiotic use in aquaculture: the Malaysian perspective. *INFOFISH-International 2/2000*:24-28.

Ulloa-Delgado, G.A., H. Sanchez-Paez, W. Gil-Torres, J.C. Pino-Renjifo, H. Rodirguez-Cruz and R. Alvarez-Leon. 1998. *Conservación y usoSostenible de los Manglares del Caribe Colombiano, Ministerio del Medio Ambiente, Asociación Colombiana de Reforestadores*, Organización Internationale de Maderas Tropicales, Santafé de Bogotá, Colombia. 212 p.

Vallejo, A. and F. Newmark. 1996. Estatus sanitario de camarones *Penaeus vannamei* cultivados en tres fincas en el Caribe Colombiano. In Silva A. and G.Merino (eds), *Acuicultura en Latinoamerica. IX congreso latinoamericano de acuicultura.* Universidad Catolica del Norte, Asociación Latinoamericana de Acuicultura, Coquimbo, Chile, pp. 172-175.

Wang, Y.G., O.L. Tan, K.L. Lee, M.D. Hassan and M. Shariff. 1999. Health management of shrimp during grow-out. *INFOFISH International 4/99*:30-36.

Williams, R.R. and D.V. Lightner. 1988. Regulatory status of therapeutants for Penaeid shrimp culture in the United States. *Journal of World Aquaculture Society 19*:188-196.

The World Bank - Netherlands Partnership Program

The World Bank
1818 H Street, NW
Washington D.C. 20433-1234, USA
Telephone : 202-477-1234
Facsimile : 202-477-6391
Telex : MCI 64145 WORLDBANK
MCI 248423 WORLDBANK
Web page : www.worldbank.org
E-mail : rzweig@worldbank.org

Network of Aquaculture Centres in Asia-Pacific (NACA)

Department of Fisheries
Kasetsart University Campus
Ladyao, Jatujak,
Bangkok 10900, Thailand
Web page : www.enaca.org
E-mail : shrimp@enaca.org

World Wildlife Fund (WWF)

1250 24th Street, NW
Washington D.C. 20037, USA
Web page : www.worldwildlife.org
E-mail : shrimp.aquaculture@wwfus.org

Food and Agriculture Organization of the United Nations (FAO)

Viale delle Terme di Carracalla
Rome 00100, Italy
Web page : www.fao.org
E-mail : FI-Inquiries@fao.org