AGRICULTURE AND ENVIRONMENTAL SERVICES DISCUSSION PAPER 09

REDUCING DISEASE RISK IN AQUACULTURE

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Food and Agriculture Organization of the United Nations

International Coalition of Fisheries Associations

WORLD BANK GROUP

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Cover Images: Courtesy of Randall Brummett. They are of aquaculture production, clockwise from the top left: Pangasius, Thailand; seahorses, Indonesia; African Catfish, Nigeria; and tilapia, Mexico.

CONTENTS

BOXES

FIGURES

TABLES

ACRONYMS AND ABBREVIATIONS

AAH	Aquatic Animal Health
ABIF	Banks and Financial Institution Association (Chile)
ACIAR	Australian Centre for International Agricultural Research
ACOTRUCH	Asociación de Productores de Salmón Coho y Trucha (Trout and Coho Salmon Producers Association; Chile)
AFD	Agence Française de Developpement (French Development Agency)
AGD	Amoebic Gill Disease
AHPNS	Acute Hepatopancreatic Necrosis Syndrome
APCM	Associação de Produtores de Camarão de Moçambique (Mozambique Association of Shrimp Producers)
ASEM	Asia Europe Meeting (of the European Union) and the Association of Southeast Asian Nations
ASH	Autorité Sanitaire Halieutique (Aquatic Animal Health Authority, Madagascar)
AQUAVETPLAN	Australian Aquatic Veterinary Emergency Plan
AVC	Atlantic Veterinary College (University of Prince Edward Island)
B-cells	Blasenzellen (secretory) cells contain digestive enzymes released in the hepatopancreas during digestion.
BAP	Best Aquaculture Practices
BMPs	Better Management Practices
CB-UEM	Centro de Biotecnologia da Universidade Eduardo Mondlane (Center for Biotechnology, Eduardo Mondlane University, Mozambique)
CORFO	National Promotion and Innovation Agency
DAFF	Australian Department of Agriculture, Fisheries, and Forestry
DAH	Department of Animal Health (Vietnam)
DGR	Daily Growth Rate
DOF	Directorate of Fisheries
E-cells	Embryonalzellen (embryonic) cells produce hepatopancreas tubule epithelial cells by mitosis.
EMS	Early Mortality Syndrome
F-cells	Fibrillenzellen (fibrous) cells are precursors of either B or R cells.

FAO	Food and Agriculture Organization of the United Nations
GAA	Global Aquaculture Alliance
GAP	Good Aquaculture Practices
GAPCM	Groupement des Aquaculteurs et Pêcheurs de Crevettes de Madagascar (Madagascar Shrimp Producer's Association)
GAV	Gill-Associated Virus
GLFA	General Law on Fisheries and Aquaculture (Chile)
HCMC	Ho Chi Minh City
HH	High Health
HP	Hepatopancreas
HPR(0-2)	Highly Polymorphic Region (0-2)
HPV	Hepatopancreatic Parvovirus
IHHN/V	Infectious Hypodermal and Haematopoetic Necrosis/Virus
IIP	Instituto Nacional de Investigação Pesqueira (National Fisheries Research Institute of Mozambique) - Mozambique
IMN/V	Infectious Myonecrosis Disease/Virus
INAQUA	Instituto Nacional de Desenvolvimento da Aquacultura (National Institute of Aquaculture Development) - Mozambique
INIP	Instituto Nacional de Inspecção de Pescado (Mozambique National Intitute for Fish Inspection)
INTESAL	Instituto Tecnológico Del Salmón (Salmon Technology Institute, Chile)
IPN	Infectious Pancreatic Necrosis
IPNV	Pancreatic Necrosis Virus
ISA/V	Infectious Salmon Anemia/Virus
LES	Laboratoire de Epidémio Surveillance (Laboratory for Epidemiological Surveillance) Antananarivo, Madagascar
LGA	Oso Farming – Les Gambas de l'Ankarana , Madagascar
MARD	Ministry of Agriculture and Rural Development (Vietnam)
MBV	Monodon Baculovirus
MPRH	Ministere de la Peche et des Ressources Halieutiques (Madagascar Ministry of Fisheries and Marine Resources)
MRC	Mekong River Commission
MTSFA	My Thanh Shrimp Farmers Association (Vietnam)
NACA	Network of Aquaculture Centers in Asia and the Pacific
NGO	Non-Governmental Organization
OIE	Organisation Mondiale de la Santé Animale, formerly the Organisation Internationale des Epizooties (World Organization for Animal Health)

OTC	Oxytetracycline
PCR	Polymerase Chain Reaction (DNA amplification and identification technique)
PCR/RT	Polymerase Chain Reaction / Reverse Transcription
PESAAQUA	Plano de Sanidade dos Animais Aquáticos (Mozambique Aquatic Animal Health Plan)
PL	(Shrimp) Postlarva(e)
PRCC	Trade Capacity Building Program
PVS	Performance of Veterinary Services
RAMA	Reglamento Ambiental de l'Acuicultura (Environmental Regulation for Aquaculture) de Chile
RAF	Responsible Aquaculture Foundation
RESA	Reglamento Sanitario de la Acuicultura (Aquaculture Biosecurity Regulation, Chile)
RIA1, 2, 3	Research Institutes for Aquaculture Nos. 1, 2 and 3 (Vietnam)
RLB	Rickettsia-Like Bacteria
RT-PCR	Reverse transciptase polymerase chain reaction
SEAFDEC	Southeast Asian Fisheries Development Center
SERNAPESCA	Servicio Nacional de Pesca (National Fisheries Service, Chile)
SIGES	Sistema Integrado de Gestión (Integrated Management System, Chile)
SPF	Specific Pathogen-Free
SRS	Salmon Rickettsial Syndrome
SUBPESCA	Subsecretaría de Pesca (Undersecretariat of Fisheries, Chile)
UAZ (APL)	University of Arizona (Aquaculture Pathology Laboratory)
UNDP	United Nations Development Program
VASEP	Vietnam Association of Seafood Exporters and Producers
WSD	White Spot Disease
WSSV	White Spot Syndrome Virus
WTO	World Trade Organization
WWF	World Wide Fund for Nature
WB	World Bank
YHV	Yellowhead Virus

ACKNOWLEDGMENTS

This study is an initiative of the Responsible Aquaculture Foundation, an independent public goods organization established by the Global Aquaculture Alliance, the Chilean Undersecretariat of Fisheries and SalmonChile, the Chilean Salmon Industry Association. The project was cosponsored by Allfish, a public private partnership between the World Bank, The Global Environmental Facility, the International Coalition of Fisheries Associations (IFCA and Profish, the World Bank's global partnership for fisheries). Inquiries should be addressed to Randall Brummett (rbrummett@worldbank.org) or James L. Anderson (jlanderson8@worldbank.org).

The authors of this study express our greatest thanks to all individuals and institutions that collaborated on this project. The Food and Agriculture Organization of the United Nations (FAO) coordinated the regional aquatic animal health workshop in Mozambique. The Network of Aquaculture Centers in Asia and the Pacific shared knowledge about the early mortality syndrome (EMS) outbreak. Dr. Lightner received partial travel funding from the central office of the World Organization for Animal Health (OIE) in Paris. Without their input this report would not have been possible.

EXECUTIVE SUMMARY

This report is the result of an international effort led by the Responsible Aquaculture Foundation of the Global Aquaculture Alliance and the World Bank to bring together, synthesize, analyze and draw practical lessons from the experience of major aquaculture disease outbreaks in Chile, Vietnam, Madagascar, and Mozambique for the benefit of stakeholders throughout the aquaculture industry. It was produced by a broad spectrum of experts and engaged a wide range of industry, government, and civil society informants.

The objective was not to compare how the case study countries found themselves with disease problems and then scrutinize their success in coping, but rather look for commonalities and exceptions in the history and structure of aquaculture in three regions of the world to elucidate key concepts in aquatic disease management and inform farmers, investors, and policy makers on how to prepare themselves for the inevitable.

CHILE

The Chilean salmon farming industry is in the process of recovering from a serious outbreak of infectious salmon anemia (ISA) which began in 2007. This outbreak caused severe impacts on Atlantic salmon production which formerly represented two-thirds of Chilean salmonid output. It also had important secondary impacts on employment, social welfare, and international market presence.

For almost three decades Chile transferred, adapted, and developed technologies, products, and markets to become the second largest producer of farmed salmon in the world, with over 500 active farming sites, creating value for the entire country and for the regions where the industry operates. However, this impressive technical and commercial success was not accompanied by matching research, monitoring, and regulation to guard against foreseeable biological risks. This imbalance impaired the industry's ability to avert and control the outbreak of ISA in 2007.

Productive, economic, and social impacts of the outbreak were magnified due to the industry's size and the rapid spread of the pathogen, facilitated by a high concentration of farms in some areas, poor husbandry, and weak biosecurity.

A rapid and well-coordinated public-private effort ensured that basic infectious disease control measures were implemented and enforced as an immediate response. In parallel, longer-term efforts involving the government, the industry, and the financial sector allowed companies to continue operating while new laws and regulations laid the foundations for the industry's renewal.

In spite of the new regulations and practices, there are still important issues to address including the need for:

- mechanisms to ensure that overconcentration of farming activity in certain areas is avoided,
- boundary definition of production zones,
- definition of zone carrying capacities,
- surveillance programs to detect and/or predict new environmental and disease issues before they can affect the industry.

Overall lessons emphasize that aquaculture depends on the capacity of biological systems to support it and that defining the aquaculture carrying capacities of bodies of water is essential in order to set limits on the maximum production in farming areas. Unless this is done, conditions will deteriorate leading to poor fish performance and eventually to disease. Also, when bodies of water are shared, regulations are required to ensure that all parties involved are good stewards of the environment and the larger the industry is the greater the risks and the harder it is to control a problem.

VIETNAM

Growing out of the transformation of over 2 million hectares of rice paddy affected by saline intrusion, Vietnamese shrimp farming, 88 percent of which takes place in the Mekong Delta, is characterized by sprawl. Some 243 thousand, 96 percent small-scale, shrimp farms cover nearly 600,000 ha of the Mekong Delta. Overall, these low-intensity farms represent 90 percent of the shrimp farming area of Vietnam, but account for only 62 percent of produce, the 10 percent of farms that employ more intensive technology producing the balance.

Low-intensity ponds maintain water quality by constantly flowing canal water through their ponds. Being open to the water supply system, all of the farms along any particular canal are effectively sharing and managing the same water. Any disease that affects one farm rapidly affects all of the others downstream. This, along with the lack of any mechanism for coordinating farmer information sharing and response to crisis, and haphazard transfer of brood and seedstock, has made the shrimp industry of southern Vietnam vulnerable to a wide range of diseases that have repeatedly infected the area.

Beginning in about 2009, a new disease, early mortality syndrome or EMS (aka: acute hepatopancreas necrosis syndrome, AHPNS) began to cause significant production losses in southern China. By 2010 the range of affected farms in China had expanded, and by 2011 EMS was confirmed in Vietnam and Malaysia, with some areas losing as much as 90 percent of their shrimp crop. EMS reached Thailand in 2012. The collateral damage to employment, social welfare, and international market presence caused by EMS/AHPNS is estimated in the billions of US dollars.

Lacking any coordinated system for sharing information with other farmers or the government, the ability of the industry to respond to crisis was limited. Rumors of what caused the disease were rampant, and millions of dollars were wasted on mistaken causes and remedies.

Initially, environmental toxins, particularly pesticides, were suspected as the cause of EMS/AHPNS. Only through a well-coordinated local and international research and farmer outreach effort based on modern technology was the source of EMS/AHPNS resolved. The disease is now known to be caused by a unique strain of a relatively common bacterium, *Vibrio parahaemolyticus,* which may be infected with a phage, a virus-like particle that inserts itself into and modifies normally harmless *Vibrio* DNA to produce highly toxic gene products that kill young shrimp.

While still ongoing, the experience of the shrimp farming sector in struggling against EMS/AHPNS in Vietnam represents a valuable case study for other sectors of global aquaculture, particularly those experiencing rapidly emerging production with lagging regulations, weak veterinary services, and a dispersed and generally small-scale farming community. It highlights the importance of collective action among and between farmers, government regulators and researchers, and the open sharing of information in identifying the causes and, thus the possible remedies, of aquatic animal diseases.

MADAGASCAR/MOZAMBIQUE

The shrimp farming industry along the Mozambique Channel is comprised of less than a dozen relatively large-scale farms, widely spaced and coordinated through strong national shrimp producer associations. The main production system is of high-value *Penaeus monodon*

destined for high-end European markets. Production systems are relatively extensive, with large amounts of water exchanged to maintain good growth rates. The isolation of these farms far from the main shrimp growing areas in Southeast Asia led regulators to believe that they could ignore the dangers of disease posed by an open water supply.

White spot disease (WSD) is a contagious viral disease of penaeid shrimp and is caused by the white spot syndrome virus (WSSV). The shrimp industries in Mozambique, and Madagascar remained free from WSD until September 2011, when a shrimp farm in Quelimane, Mozambique, experienced an outbreak. Since then, the industry in Mozambique has virtually shut down. Eight months later, there was an outbreak of WSD in Madagascar at a farm north of Morondava, which is still out of service. Another infected Malagasy shrimp farm has been extensively modified with upgraded filtration and disinfection systems and now seems to be operating well, while a third has experienced another outbreak and is currently being upgraded. The disease is believed to have come via ballast water from previously infected areas along the Arabian Peninsula.

Recovery from the WSSV crisis will require several changes at the farm level, the single most important of which is to eliminate the use of wild broodstock. This will require the establishment of breeding programs to develop Specific pathogen-free (SPF) broodstock. As a long-term strategy, SPF broodstock should be selected for resistance to WSSV. This is a time-consuming and expensive process that may be beyond the means of individual farms. Needed is a regional breeding center to produce SPF broodstock that are genetically selected for resistance to WSSV.

The second most important change that farms can make is to reduce or eliminate their dependence on water exchange. The most effective way of accomplishing this is to install aeration systems in the ponds. Biosecurity on shrimp farms can also be improved by avoiding stocking during the winter months, filtering incoming seawater using screens of 200 microns or less, chlorinating ponds after initial filling, and installing crab fences and bird netting.

At the national level the regulatory framework needs to be upgraded to include a comprehensive aquatic animal health (AAH) policy, an adequately funded regulatory agency and a national reference laboratory. National AAH plans should be developed to clearly identify the role of each stakeholder in a national biosecurity program and the strategies for responding to disease outbreaks. Disease surveillance programs consistent with OIE standards should be set up and funded nationally. There is a strong need for capacity building in the public sector with respect to aquatic animal health management. Priority should be given to promoting collaboration between the producer associations and the government ministries in the development of national biosecurity policies and programs.

As problems affecting one side of the Mozambique will inevitably affect the other side as well, the national AAH plans of Mozambique and Madagascar should be integrated to form a regional AAH plan. Regular meetings between stakeholder groups of both countries should be scheduled to allow for the sharing of information and the discussion of cooperative projects, such as the development of a regional breeding center and the sharing of surveillance data.

COST-BENEFIT OF BIOSECURITY

Losses to the aquaculture industry globally are estimated by FAO at about US$6 billion annually. The ISA outbreak in the Chilean salmon farming industry cost US$2 billion dollars and 20,000 jobs. The EMS outbreak in the Mekong Delta is costing what are mostly small-scale producers about US$800 million per year that they cannot afford, and this does not include the unknown number of jobs lost in the rest of the shrimp value chain. Losses from WSSV outbreaks in Asia were estimated at US$6 billion during outbreaks in 1992–93 and US$1–2 billion during 1999 outbreaks in Latin America.

Diseases are ubiquitous and pretending outbreaks will not happen because they have not happened is not rational. Suiss-RE, a major agricultural crop insurer, calculates that the average insurance loss ratio for aquaculture over the period 1992–2012 was 65 percent and

disease accounted for 20 percent of that (in the relatively well-managed salmon farming industry). Most aquaculture disease outbreaks have occurred in developing countries where over 90 percent of aquaculture takes place, reducing revenues, eliminating jobs, threatening food security, and undermining development goals. The generally small-scale and rural nature of aquaculture in developing countries means that the vast majority of diseases go undiagnosed, untreated, and undocumented, imposing an enormous burden on communities working to escape poverty.

Required investments in biosecurity to minimize the risk of disease outbreaks will vary according to place and scale. The need for improved diagnostic and surveillance capacity of national veterinary services is one common element among all case studies. The establishment of a national and/or regional platform for communication between government and farmers is also important, but less costly. Apart from these governmental investments, in Chile, major costs for salvaging the salmon industry were associated with relocation and restocking of farm installations, costs borne mostly by the private sector.

In Vietnam (and Southeast Asia more generally), the farm-level investment needed to manage EMS is not yet known, but government investment in affordable three-phase electricity would help lift constraints to the ability of lower income farmers to reduce their dependence on high levels of water exchange. Providing assistance to establish a forum for communication and cooperation among the hundreds of thousands of farmers that share a contiguous water supply will also improve monitoring of, and compliance with, farm-level and regional biosecurity protocols.

Along the Mozambique Channel, farm-level improvements in biosecurity have been estimated at between US$6 and 14 million, depending upon the level of security. A basic system includes stocking SPF shrimp postlarvae (PLs), crab fencing, bird netting, probiotic usage, and structures to allow drainage of seawater distribution canals. Reducing stocking rate to allow reduced water exchange is probably unprofitable. The addition of aeration plus bag filtration increases productivity, reduces overall operating costs, and improves the profit margin. Net returns per kg of shrimp produced are estimated at US$1.25/kg with no biosecurity plan and US$2.00/kg under this strategy. The most biosecure strategy, in which aeration and microscreen drum filtration is used, is very capital intensive with an expected investment cost of about US$14 million for a 400 ha-farm. Despite the high cost, the profit per kg of shrimp is reduced by only US$0.12/kg.

CONCLUSIONS AND RECOMMENDATIONS

From review of case study findings, it is clear that there are several key structural and behavioral attributes of the aquaculture industry that make it vulnerable to disease. First and foremost is that disease management transcends the boundaries of individual farms. Area management systems are essential. It is also clear that, while the species, production systems, participants, and institutions involved in the operation and regulation of aquaculture vary from place to place, the science and logic that can reduce the incidence and severity of disease are common throughout the industry.

Conditions that lead to disease include: (1) close proximity among farming operations and/or shared water supply and discharge; (2) unregulated transfer of animals and/or gametes among farms and from sites outside of the farming area; (3) lack of adherence to on-farm sanitary protocols; (4) inadequate diagnostic and veterinary services; and (5) failure of farmers to share information and cooperate in collective action to respect best management practices and respond to crises.

Corrective measures to avoid or moderate diseases in aquaculture respond directly to the causative conditions: (1) regulate the density of farms within a designated zone so as to avoid sharing of water inputs and outfalls; (2) quarantine and carefully control movement of culture animals into the zone and between farms once introduced; (3) adoption of best aquaculture practices at farm level to reduce stress and improve animal welfare; (4) strengthen veterinary services to provide basic diagnostics and guidance to farmers; and (5) structure dialogue among farmers and between government and farmers to improve knowledge and compliance, while reducing free ridership.

As a first step in addressing constraints to aquaculture disease management, a review of the existing aquatic veterinary services is recommended. The OIE conducts standardized reviews of veterinary services that can identify opportunities to improve performance and capacity, and collect data for cost-benefit analysis of investments in improved biosecurity.

As disease is not simply a matter of the presence or absence of pathogens, veterinary services to aquaculture need to move beyond the laboratory to explore the host-agent-environmental triad that creates the necessary conditions for disease and can illuminate management planning.

Knowing the carrying capacity of the ecosystems of which aquaculture is a part is crucial to scaling of the industry that operates within it. Data and analysis are required at the local level to adapt general carrying capacity models to local conditions and the preferences of local communities.

Estimation of the carrying capacity of the watershed or water body in which aquaculture is being conducted requires spatial mapping of production systems and their related hydrology. As the single greatest constraint to proper disease management in aquaculture is the lack of cohesion and cooperation among producers, encouraging management planning at the ecosystem, rather than farm, level serves not only to define the space over which biosecurity rules should be implemented, but creates a context in which farmers may be better able to understand the need for collective action.

The primary lesson of these case studies is that aquaculture disease management goes beyond the limits of individual farms and requires a collective zone management approach. The salmon industry has, sometimes painfully, learned this lesson and is now raising itself to a new, more sustainable, level in Chile and elsewhere. Globally, shrimp farmers and other aquaculture producers who share a waterbody with their neighbors, need to reflect on the examples of Chile, Vietnam, Mozambique, and Madagascar and take steps to improve coordination among farmers and between the farming community and regulators so as to better manage the ecosystems in which they operate. Only through an ecosystem approach can the industry reduce volatility, improve profitability, and approach greater sustainability.

Chapter 1 INTRODUCTION

RANDALL BRUMMETT, Senior Aquaculture Specialist
THE WORLD BANK

There are thousands of rickettsial, viral, bacterial, protozoan, and metazoan parasites that cause disease in farmed aquatic animals. According to the Food and Agriculture Organization (FAO), disease outbreaks cost the global aquaculture industry some US$6 billion per year and represent the major farm-level risk. The shrimp industry alone has suffered losses on the order of US$10 billion since 1990 and new diseases are appearing every year. Vietnam alone reports losing an average of US$1 billion per year to disease. The Chilean salmon farming industry is in the process of recovering from a severe outbreak of infectious salmon anemia virus (ISAV) which began in 2007 and cost 350,000 to 400,000 tons of fish, US$2 billion, and 20,000 jobs. Virtually all of these catastrophes have occurred in developing countries where over 90 percent of aquaculture takes place, reducing revenues, eliminating jobs, and threatening food security. The fact that most aquaculture is small-scale, rural, and found in developing countries means that the vast majority of diseases go undiagnosed, untreated, and undocumented, imposing an enormous burden on communities working to escape poverty.

The Global Aquaculture Alliance has estimated that US$100 billion of new investment might be needed to meet the global food security and rural development objectives set out for aquaculture. Many investors want to engage in aquaculture, but hesitate in the face of risk. According to Suiss-RE, a major agricultural crop insurer, the average insurance loss ratio for aquaculture over the period 1992–2012 was 65 percent and disease accounts for 20 percent of total losses in the relatively well-managed salmon farming industry.

Diseases do not stay on farms. While the basics of farm-level disease management are known, the interconnectedness among aquaculture installations and between aquaculture and the external environment means that only a few careless farms can ruin an industry. The sector-level biosecurity and response planning that is needed to address problems beyond the farm gate require communication and cooperation among farmers, extension personnel, veterinary services, and government regulators.

Considering the gravity and frequency of fish disease outbreaks, guidelines on the development and implementation of national policies for their prevention, detection, and management are urgently needed. Hampering this is the lack of a comprehensive overview of the practical ways and means of regulating aquaculture that would permit both governments and aquaculturists to: (1) calculate the cost-benefit ratio of investments in disease control and, (2) find a cost-effective strategy for the implementation of best practices.

1.1 THE STUDY

This initiative was launched by the Responsible Aquaculture Foundation of the Global Aquaculture Alliance and the government of Chile to provide guidance to the global aquaculture industry on practical measures to ensure biosecurity from some key, well-documented epidemics with a specific focus on south-south experience sharing to support political momentum for change. This report should be of particular interest to the private sector, the public sector, and civil society in those many developing countries where aquaculture is expanding rapidly, but where regulatory frameworks, including aquatic animal health services, are weak. From the point of view of the World Bank, these lessons contribute directly to rural policies in support of enhanced and more economically, socially, and environmentally sustainable food production systems and help secure employment through stable aquaculture and fisheries, value chains.

Methodology

The study is based on review of published and unpublished data supplied by the Chilean, Vietnamese, Malagasy, and Mozambican authorities, researchers, and local aquaculture investors and other stakeholders. Meetings were held, production sites and research stations visited, and documents collected in each country and reviewed by each expert team. These were subsequently discussed via teleconferences among the study team and with the many informants who contributed their knowledge and experience to the analysis. To ensure confidentiality in what has been a sometimes fraught relationship among and between private-sector actors, governments, and civil society, we do not identify our sources in the document.

The analysis considered the following elements (emphasizing pre- and post-crisis comparison):

- *Science and technology:* with emphasis on environmental and epidemiological research, monitoring, and management.
- *Production factors and value chain:* emphasizing production practices and general models applied in the case study countries.
- *Market development:* evolution of products and market leading up to and through crisis.
- *Social issues:* impact of regulation and/or failure to regulate on community and workers.
- *Governance and regulations:* principal regulations and institutional aspects.
- *Investment and financing:* evolution of investment and financing during the crisis.

Case Study Diversity

The selection of case studies was guided by the need to explore disease outbreaks in a range of geographical and industrial development scenarios. The three case studies capture the breadth and depth of experience among farmers and governments confronted with catastrophic disease outbreaks in aquaculture. The study teams arrived at different times in the progression of the outbreak and found that government and industry were at different stages of preparedness to act. The differences reflect various stages in the development of regulatory frameworks and industry coordination. In Chile, the study began when most remedial action had already been taken, so there is a clear emphasis on the way in which government and a well-organized private sector worked together to solve problems. In Vietnam, the study team was actively trying to understand how early mortality syndrome (EMS) became so problematic without even knowing the exact cause. The ability to take decisive action was constrained by the disorganized and generally small-scale nature of the Vietnamese shrimp industry. Consequently, the emphasis in this case is on the experience of the industry and government in assembling objective data and building the public-private partnership for disease management that is already well-advanced in Chile. Along the Mozambique Channel, a well-known and understood disease took by surprise a small and well-organized industry, teaching lessons about how individual farms manage biosecurity.

The objective was not to compare how the case study countries found themselves with disease problems and then scrutinize their success in coping, but rather look for commonalities and exceptions in the history and structure of aquaculture in three regions of the world to elucidate key concepts in aquatic disease management and inform farmers, investors and policy makers on how to prepare themselves for the inevitable.

Expert Team Members

Noriaki Akazawa. Noriaki Akazawa graduated from Hokkaido University where he majored in Microbiology and Fish Diseases. From 1983 to 1998 he worked as a seafood purchaser and later as seafood processing plant manager in Japan, Bali, and Vancouver. In 1999, Akazawa joined Song Cheng Enterprises Sdn. Bhd., a Malaysian shrimp farm operated by the Skylark Japan restaurant chain as Culturing and Processing Director. In 2000, he was promoted to Managing Director. Song Cheng was bought by Agrobest Sdn. Bhd. and Akazawa stayed on as Managing Director. He has now been managing the shrimp farm and processing plant for 15 years and has increased shrimp production from a few hundred to more than 11,000 metric tons despite the presence of a variety of shrimp diseases. Akazawa has become a world leader in managing this disease, which he is studying for a Ph.D. degree at Kinki University.

Adolfo Alvial is a Marine Biologist from the University of Chile, who received a Masters in Oceanography from Oregon State University and an MBA from Universidade Adolfo Ibáñez. He was Professor and Secretary General at the University of Chile-Iquique, where he conducted research on pelagic fisheries and El Niño. In 1987 he joined Fundación Chile as Director of Aquaculture. In that position he led several projects to develop new business opportunities for the country such as turbot, abalone, and hake. In 2002 Alvial was appointed as General Manager of the Technological Institute of salmon, the technical branch of the Chilean salmon association. Between 2007 and 2010 Alvial was Technical Director of Marine Harvest Chile S.A. He has been President of the Business Incubator INER, Los Lagos since 2006 and is presently General Director and co-owner of his own consulting company, Adolfo Alvial Asesorías S.A. Alvial has participated in several initiatives to develop standards for aquaculture, such as Best Aquaculture Practices (BAP) salmon standards for the Global Aquaculture Alliance (GAA) and greenhouse gas emission standards in the seafood industry.

Pierre-Philippe Blanc is Technical Assistant of APCM (Associação de Produtores de Camarão de Moçambique), the Mozambican shrimp producers association, and Project Manager for the French Development Agency (AFD) Project: Programme de Renforcement des Capacités Commerciales (Reinforcement of Commercial Capacities Program) in Mozambique. Prior to coming to Mozambique, Blanc was providing technical services to the Post-Harvest Development and Quality Division (including laboratories and competent authorities) of the Fisheries Department (Ministry of Industry and Primary Resources) in Brunei Darussalam. He has worked in shrimp aquaculture production, R&D, quality management, environment and nutrition in the Indian Ocean subregion for more than 10 years. His university background includes an MSc in Natural Resource Management (Cranfield University), a Diploma in Agronomic and Economic Development (ISTOM), and an ISO Auditor Certification.

José Miguel Burgos has degrees in Veterinary Medicine and Leadership Skills and Strategies from the Universidad de Chile. Burgos is currently Head of the Aquaculture Division at the Chilean Undersecretariat for Fisheries. His past positions include Managing Director at Aquagestión S.A., Technical Manager at Recalcine Laboratory, and Head Veterinarian at the Chilean National Fisheries Service where he conducted studies in the area of managerial direction, quality service, goal-oriented project planning, epidemiology, and the analysis of risks associated with aquatic disease at national and international levels. He is a member of the National Committee on Aquatic Animal Disease and also works on a number of international initiatives of the Chilean government, in particular, the Chilean representation to the Organisation Internationale des Epizooties (OIE) and the Expert Technical Commission on Aquatic Animals. Burgos worked on biosecurity aspects of trade negotiations between Chile, the United States, and the European Union. He has participated in the development and registration of veterinary drugs and vaccines to control ISA virus and other fish diseases.

George W. Chamberlain received his PhD in aquaculture from Texas A&M University. In 1990 he joined Ralston Purina Inc., where he directed its international aquaculture program. In 1998, he joined Monsanto Inc., where he directed its marine shrimp program on genetic selection, soy-based feeds, and sustainable pond systems. In 1999, he and Ken Morrison developed Black Tiger Aquaculture, a successful 170-ha integrated shrimp farm in Malaysia that had failed due to WSSV under previous ownership. They managed WSSV through development of an specific pathogen-free (SPF) population of *Penaeus monodon*, family-based breeding, all-in/all-out larval rearing, and zero water exchange ponds. In 2004, they established Integrated Aquaculture International Inc. (later rebranded as iAqua), a breeding and technology company with white shrimp operations in Hawaii and black tiger shrimp operations in Brunei. Chamberlain served as President of the World Aquaculture Society in 1996. In 1997, he led the formation of the Global Aquaculture Alliance, an organization dedicated to the sustainability of aquaculture, which he continues to serve as President. In 2010, he assisted in the formation of the Responsible Aquaculture Foundation.

John Forster worked on shrimp aquaculture for the UK government from 1965 to 1973 and then joined Shearwater Fish Farming Ltd, a subsidiary of The British Oxygen Company, for whom he established and ran a commercial trout farm and an international technical services business. In 1984, he moved to the United States to set up Stolt Sea Farm's U.S. West Coast salmon and sturgeon farming operations before starting his own consulting practice

in 1994. In that year, he also founded Columbia River Fish Farms LLC, now the largest U.S. producer of steelhead trout, from which he divested in 2005. As a consultant, he responds to the needs of public and private sector clients, and has a special interest in how the lessons learned in aquaculture over the last 45 years can be applied to aquaculture development in the years ahead. He is a recently retired member of NOAA's Marine Fishery Advisory Committee, serves on the executive committee of Aquaculture without Frontiers, and serves or has served on the boards of several private aquaculture companies. He is a past president of the Washington Fish Growers Association and former U.S. representative to the International Salmon Farmers Association.

Tung Hoang is an Associate Professor at the International University (IU) in Ho Chi Minh City, Vietnam. Hoang has 20 years of experience in aquaculture education and development, particularly shrimp research and farming in Australia, Thailand, and Vietnam. He served the World Aquaculture Society as President of its Asian Pacific Chapter during 2006–08. His research interests include shrimp broodstock management, larval rearing techniques, aquaculture system design, and zonal management. Since early 2011, Hoang's research has focused on the early mortality syndrome in penaeid shrimps, ecological measures for pond management to overcome shrimp disease outbreaks, and most recently, the development of an intelligent system for effective zone management of shrimp farming in the Mekong Delta of Vietnam named "MTC®TOMBOOK." Hoang is currently leading the School of Biotechnology of IU and would like to advance shrimp farming in Vietnam via the assistance of modern biotechnology and communications technology. He established the Aquatic Resources Management Program at IU in 2010 to provide more quality manpower for the local aquaculture sector. Hoang has worked actively in the field as an independent consultant for international agencies/companies and also as a local shrimp farmer to enhance his knowledge and experience, and more importantly for the development of practical solutions for shrimp farming.

Rolando Ibarra, fish health specialist, INTESAL-SalmonChilen (Chile). Rolando Ibarra holds a DVM from Universidad Católica de Temuco (Chile) and is an expert in health management and diseases of aquatic organisms. He began his career as a technician in fish disease diagnostics and then joined the Faculty of Veterinary Medicine of Universidad Católica de Temuco (Chile) as a full-time researcher focusing on diseases of salmonids in the freshwater stage of their production cycle. In 2008 he joined the Salmon Research Institute—a think tank from the Chilean salmon farming industry —as head of the Health and Production area during the ISA virus crisis. Throughout the ISA crisis in the Chilean salmon industry, he coordinated and managed working groups with farms, processing plants and service suppliers to implement best aquaculture practices to mitigate and prevent further ISA epidemics in the industry. He participates as a representative of the Chilean Salmon Producers Association (SalmonChile) in strategic public-private boards that address the main sanitary challenges of the Chilean salmon industry. He currently coordinates all the activities and research related to fish health in the Salmon Research Institute, with special emphasis on sea lice, salmon rickettsial syndrome (SRS), ISA, and surveillance systems. He has participated in several research projects with public and private funds in the area of health management, fish pathology, nutrition, and epidemiology, in Chile and abroad.

Le Van Khoa is Chief of Aquatic Animal Health Management in the Vietnamese Ministry of Agriculture and Rural Development and serves as the OIE/Network of Aquaculture Centers in Asia and the Pacific (NACA) Focal Point for Aquatic Animal Diseases in Hanoi. He obtained his BS in Aquaculture in 1997 from Hanoi Agriculture University and Nha Trang University of Fisheries, and a PhD in Veterinary Medicine in 2005 from Nippon Veterinary and Animal Science University. He started his career as a fish pathologist at the Research Institute for Aquaculture No.1 in 1997 where he served as head of the Fish Disease Laboratory from 2006 to 2008. His major research interest is fungal diseases of aquatic animals, but has experience in best management practices, poverty policy, and national aquatic animal health planning. Khoa has been involved in a series of national and international studies on EMS/acute hepatopancreatic necrosis syndrome (AHPNS) since the first case of infection was observed in Vietnam. Currently, he is also vice chairperson of the Fish Health Section of the Asian Fisheries Society and an invited lecturer at the Hanoi University of Agriculture.

Fred Kibenge has a Bachelor of Veterinary Medicine degree from Makerere University (1978), a PhD in Animal Virologyfrom Murdoch University (1983) and is now professor of virology, and chairman

of the Department of Pathology and Microbiology at Atlantic Veterinary College, University of Prince Edward Island. He has studied Infectious Salmon Anaemia since its first occurrence in Eastern Canada in 1997. His laboratory confirmed the first occurrence of ISA in farmed Atlantic salmon in Chile in July 2007 and characterized the virus responsible for the 2007–10 ISA epizootic. Kibenge undertook extensive post-doctoral research in virology at the University of Liverpool, Washington State University and Ohio State University. He is a diplomat of the American College of Veterinary Microbiologists. He has published extensively on the detection and virology of ISAV, and has spoken on these subjects at various international fora.

Donald V. Lightner is a shrimp pathologist in the Department of Veterinary Science and Microbiology at the University of Arizona. Professor Lightner's career in diseases of farmed aquatic animals spans more than four decades. After completing his M.S. and Ph.D. degrees in Fish Pathology, he began the first shrimp pathology program in the United States at the NMFS Laboratory in Galveston, Texas. In 1975 he accepted a research position at the University of Arizona where he applied shrimp disease management methods to a prototype superintensive production system. Since 1986, he has been a professor of Veterinary Science and Microbiology. He has authored or coauthored more than 500 publications and presentations on pathogen detection, disease diagnosis, and pathobiology in penaeid shrimp. He has trained over 20 graduate students. Some 1,500 professionals from 59 countries have received formal training in shrimp pathology and diagnostic methods in 27 of his Shrimp Pathology Short Courses and 39 special international workshops. His laboratory became an OIE Reference Laboratory in 1993. He has served as a member or adviser to the Aquatic Animal Health Standards Commission for 12 years and contributed to the current editions of the Aquatic Animal Health Code and Manual of Diagnostic Tests for Aquatic Animals.

Nguyen Van Hao earned a PhD in Fish Physiology in Russia in 1994 and completed various training courses in applied quantitative genetics, fish/shrimp health management, and rural extension. He is currently Director of the Research Institute for Aquaculture No. 2 of the Ministry of Agriculture and Rural Development in Vietnam. Hao started his professional career in the Ministry of Fisheries in 1979, focusing on aquaculture farming, breeding and selection, aquatic animal health management, aquaculture engineering, and aquaculture extension. Hao's broad experience as a scientist, aquaculturist and extensionist give him a unique knowledge of the development of Vietnamese aquaculture and fisheries, especially in the Mekong Delta. He has served as project coordinator for various provinces, ministries (Fisheries, Agricultures, and Rural Development, Science and Technology), international institutions, and universities including the United Nations Development Program (UNDP), NACA, Mekong River Commission (MRC), Australian Centre for International Agricultural Research (ACIAR), World Fish Center, Southeast Asian Fisheries Development Center (SEAFDEC), Norad, Danida, Sida, Asia Europe Meeting (of the European Union) and the Association of Southeast Asian Nations (ASEM), Aquaculture Platform, Stirling University, Ghent University, Wageningen University, and Queensland University of Technology. Dr. Hao has published books related to shrimp farming, shrimp health management, and fishing gear in the Mekong Delta, as well as a number of scientific articles in both national and international peer-reviewed journals.

Hamisi Lussian Nikuli is Director of Aquaculture and National Coordinator of Aquatic Animal Health in the Tanzanian Ministry of Livestock and Fisheries Development. Nikuli worked as Head of the Department of Agriculture, Livestock and Fisheries in the Newala Local Government Authority from 1998–2012. Nikuli is a registered Veterinarian and a member of the Veterinary Council of Tanzania. He has a Master of Veterinary Medicine (MVM) in Aquatic Animal Health from the Norwegian School of Veterinary Science and a Bachelor of Veterinary Medicine from Sokoine University of Agriculture. For 23 years, Nikuli has been directly involved in animal health and production, policy implementation and planning.

Isabel Omar has been the Director of the Mozambican National Institute for Aquaculture Development (INAQUA) since its creation in 2005. She was previously the head of the Aquaculture Department and head of the Fish Inspection and Quality Control Department, both at the Ministry of Fisheries. Omar is also the current Chair of Committee for Inland Fisheries and Aquaculture in Africa (CIFAA) and a Lecturer at the Veterinary School of Eduardo Mondlane University. Her formal education includes an MSc in Shellfish Biology & Culture (University of Wales) and a BSc in Biology, Stock Assessment, and Management from Eduardo Mondlane University.

Luc Ralaimarindaza has worked for 20 years as a veterinarian in the Malagasy Department of Veterinary Services. In 2006, he became head of the Technical Department responsible for the management, supervision and implementation of export inspection and approval and epidemiological surveillance of shrimp aquaculture in the Autorité Sanitaire Halieutique (ASH), where, since November 2010, he has been the Executive Director. Since the first occurrence of white spot disease in Madagascar Ralaimarindaza has been raising awareness within the Malagasy government of the economic impact of WSD and is leading the government in the establishment of sanitary barriers, implementation of regulatory measures, treatment of waste and effluents in crustacean processing plants, and strengthening biosecurity in aquaculture farms.

Melba B. Reantaso is an Aquatic Animal Health Professional with more than 35 years of professional experience. She has a PhD and postdoctoral qualifications from the University of Tokyo and Nippon Veterinary and Animal Science University. Taking early retirement from her post as Senior Aquaculturist in the Philippine Bureau of Fisheries and Aquatic Resources, she joined NACA as Regional Aquatic Animal Health Management Specialist from 1999–2002. She migrated to the United States in 2002 and worked as Molluscan Pathologist at the Oxford Laboratory in Maryland before joining the Food and Agriculture Organization of the United Nations (FAO) in 2004 as Aquaculture Officer. At FAO, Reantaso is in charge of aquatic animal health/biosecurity. She led several aquatic disease emergency investigations (for example, Koi herpesvirus in Indonesia, Epizootic ulcerative syndrome in Africa and EMS of shrimp in Vietnam. Currently she is Lead Technical Officer of projects in Suriname, Indonesia, the Western Balkans, and developing two inter-regional (Asia and Latin America) projects on infectious myonecrosis virus (IMN/V) and EMS. She is also involved in assisting FAO members in developing national and regional strategies on aquatic animal health as well as conducting introductory courses on risk analysis for aquatic animal movements.

Sophie St-Hilaire received her veterinary degree from the University of Prince Edward Island in 1994 and completed MSc and PhD degrees in veterinary epidemiology at the University of Saskatchewan and the University of Guelph, respectively. She is currently Associate Professor and holds the Canadian Research Chair at the Atlantic Veterinary College (AVC). She has worked in the field of aquatic animal health for over 20 years and has published more than 50 peer-reviewed articles on topics ranging from fish nutrition to infectious disease control and surveillance. Prior to AVC she worked for a number of government agencies including the Department of Fisheries and Oceans in Canada; University of Guelph; the Centre for Environment, Fisheries & Aquaculture Science in the United Kingdom; and Idaho State University. She has been involved in a number of fish disease outbreak investigations ranging from viral to parasitic in origin in both wild and farmed animal populations. She has also been actively involved in developing a number of surveillance programs for monitoring pathogens and assessing disease control strategies. In 2010 she worked with SalmonChile on designing a containment plan for ISA and infectious disease risk management for salt water salmon farms in Chile. Since her appointment at the AVC she has worked on several bivalve and invasive species projects for Prince Edward Island as well as continued with projects on salmonid disease control.

Richard (Dick) Towner is a genetics and breeding consultant working with major trout, shrimp, and tilapia companies to improve stocks through genetic selection. He did his undergraduate work at Colorado State University and received his MS and PhD degrees from the University of Wisconsin. Prior to starting his consulting company, Towner was Director of Genetics Research at H&N International GmbH for 22 years. From 1978 through 1999, Towner had an affiliate faculty appointment in the School of Fisheries at the University of Washington.

Tran Huu Loc is an Assistant Professor at Nong Lam University at Ho Chi Minh City, Vietnam, working in aquaculture pathology in Vietnam since 2006. While a PhD student at the University of Arizona, he was part of the team that discovered the causative agent of EMS/AHPND in 2013. He is also a Senior Consultant for Minh Phu Seafood Corp., Vietnam, the largest shrimp company in the world. He is the founder and Director of the Minh Phu AquaMekong Shrimp Vet Laboratory, the very first shrimp research center in Vietnam. Recently, Loc developed technologies for the production of EMS/AHPND-free postlarvae and methods to control the disease in shrimp farms. Those findings are waiting for patents.

Peter M. Van Wyk has an MS degree in Aquatic and Population Ecology from the University of California, Santa Barbara (1981), and a Master of Aquaculture degree from Auburn University (1986). While at Auburn, Van Wyk trained as an aquaculture economist, manager, and analyst. During his 30-year career in aquaculture Van Wyk has designed, built, and managed shrimp hatcheries and grow-out facilities in the United States, Latin America, and Malaysia. Van Wyk has spent much of the last 15 years developing technology to rear shrimp in biosecure indoor production facilities. As a project planner, he has used his expertise in production management, engineering, and aquaculture economics to develop sophisticated bioeconomic spreadsheet models to evaluate how changes in production strategies and performance parameters affect project costs and profitability. He has published several papers on the economics of recirculating shrimp production systems.

Marcos Villarreal has a BS degree in Biology and a Master's in Business Administration. He started his career in shrimp aquaculture in 1986 as Manager of the Nursery System at Agromarina de Panamá S.A. (Ralston Purina), where he became Operations Manager in 1994. In 1997, he was hired as General Manager of Industrias Acuimar S.A. In 2005, he moved to Indian Ocean Aquaculture in Pemba, Mozambique. In his role as Assistant General Manager, he managed the shrimp hatchery and assisted the General Manager in processing plant operations. From 2006 to 2012, Villarreal served as General Manager of Arabian Shrimp Company in Gizan, Saudi Arabia, since which time he has served as General Manager of Altrix de Panama, S.A. (Grupo Calesa/Camaronera de Coclé S.A.). He was President of the Panamanian Shrimp Growers Association from 1995 to 1997 and is an internationally recognized expert in the management of WSSV.

Chapter 2 CASE STUDY I: THE INFECTIOUS SALMON ANEMIA OUTBREAK IN CHILE

ADOLFO ALVIAL FREDERICK KIBENGE JOHN FORSTER
JOSÉ M. BURGOS ROLANDO IBARRA SOPHIE ST-HILAIRE

OUTLINE

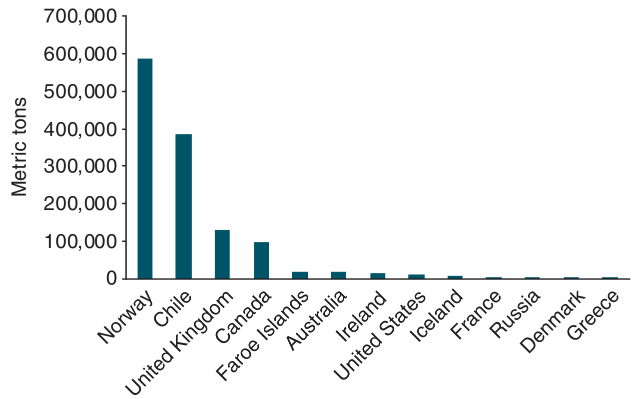
2.1 ORIGIN AND EVOLUTION OF THE SALMON FARMING INDUSTRY IN CHILE

Industry Development Phases

Salmon farming in Chile started at the end of the 1970s. Fundación Chile, a nonprofit technology stimulation group, played a vital role in importing and transferring aquaculture technology to support the growth of the Atlantic salmon (*Salmo salar*) farming industry based largely in Region X (Los Lagos), some 1,100 km south of the capital, Santiago. This is a relatively young industry, 1991 being the first year when production exceeded 10,000 tons, but by 2005, Chile was the fastest-growing salmon producer in the world, having overtaken Scotland (in 2000) as the second largest producer of Atlantic salmon (figure 2.1) and was on a course to overtake Norway. This rapid development, which can be characterized by the phases shown in figure 2.2, resulted in a noticeable cluster of saltwater farms in the areas around Puerto Montt, Chile. Production and export of product from 2001 to 2011 are shown in figure 2.3.

In 2007, the industry generated around 25,000 direct jobs and 20,000 indirect jobs associated around a nucleus of some 40 companies and more than 1,200 input suppliers. As mentioned above, much of the production was concentrated in the coastal areas of Region X, most notably along the central and east coasts of Chiloé Island, where approximately 40 percent of total salmon production was concentrated (figure 2.4).

FIGURE 2.1: Total Reported Atlantic Salmon (*Salmo Salar*) Aquaculture Production in 2005 (FAO 2007)



This rapid growth was accompanied by gradual development of regulations (figure 2.5):

- *The Fishery and Aquaculture Law* with its three major sectorial regulatory bodies: (1) the Environmental Regulation of Aquaculture (RAMA); (2) the Sanitary Regulation of Aquaculture (RESA); and (3) the Regulation for Aquaculture Licenses.

FIGURE 2.2: Evolution Phases of the Chilean Salmon Industry (Alvial 2011)

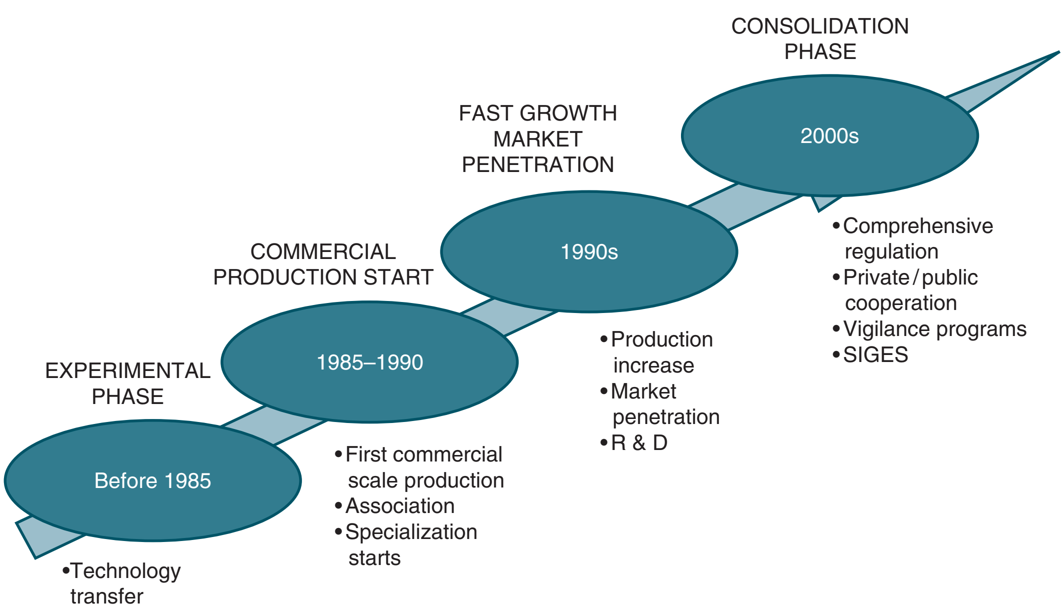
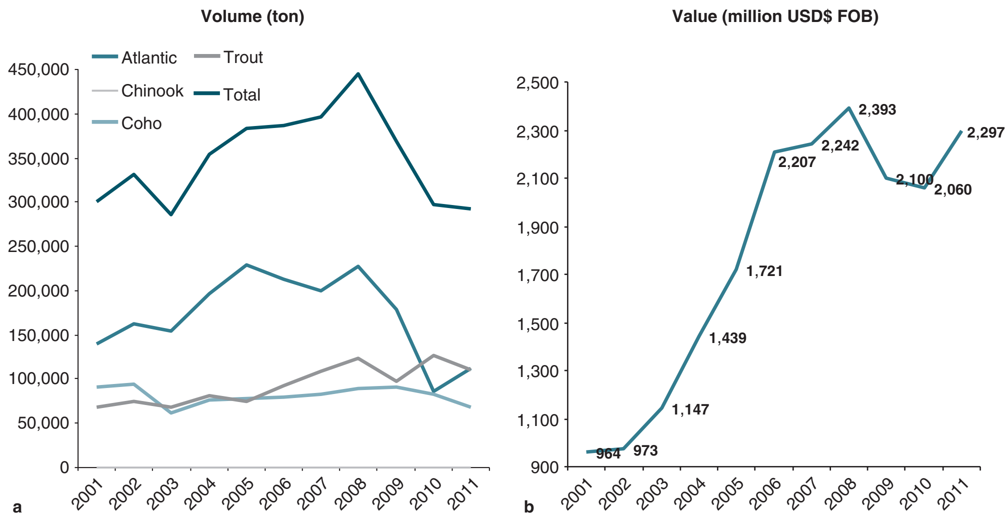


FIGURE 2.3: Volume (a) and Export Value (b) of the Chilean Salmonid Aquaculture Industry 2001–11 (Alvial 2011)



- *The General Basis for Environment Law,* which has several aspects connected to aquaculture, particularly rules for environmental impact assessment.
- *The Navigation Law,* principally aspects related to coastal waters, land use, and pollution control.
- Only in the last decade can the regulations be considered to have been reasonably well integrated and complete.

FIGURE 2.4: Distribution of Seawater Salmon Grow-out Farms in Chile (Regions X and XI) Comparing 2006–07 (Pre-ISAV) vs. 2009–10 (Post-ISAV) (after O Gárate unpublished)

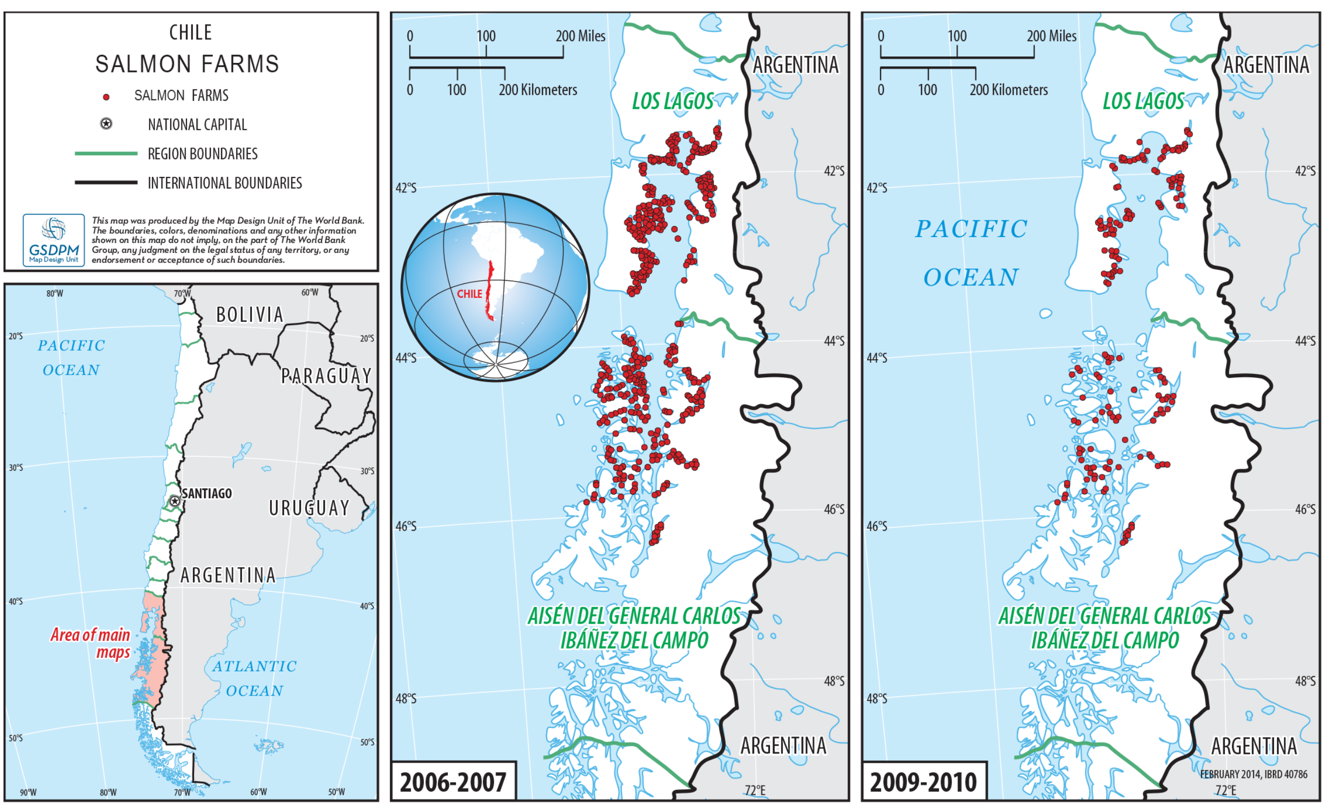
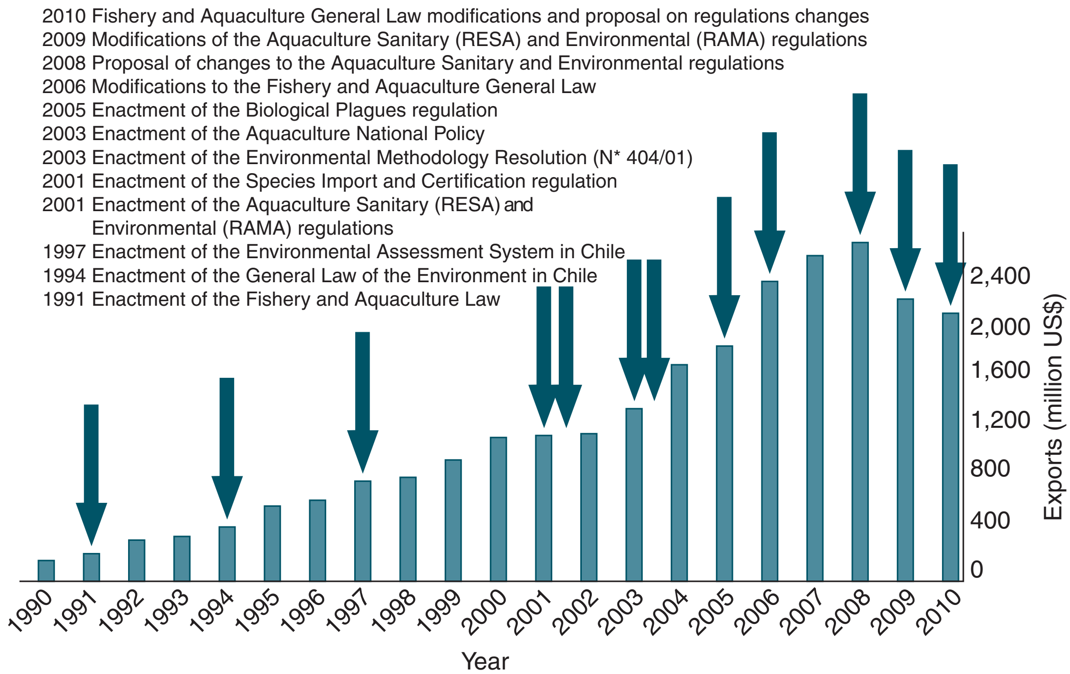


FIGURE 2.5: Evolution of Aquaculture Regulations in Chile Relative to Export Volume (Alvial 2011)



Production Systems

Depending on the salmon species and life stage (egg, fry, smolt, saltwater grow-out, or broodstock), fish facilities are located in rivers, lakes, estuaries, or coastal sites near shore.

There are some 30 saltwater grow-out companies with licenses to produce fish at 1,041 sites in the coastal waters of Chile. In 2007, 533 of these sites were active, approximately 72 percent of which are located in Region X, 27 percent in Region XI, and 1 percent in Region XII (SERNAPESCA 2008). The salmon species farmed included Atlantic salmon (*Salmo salar*), Coho salmon (*Oncorhynchus kisutch*), rainbow trout (*O. mykiss*), and Chinook salmon (*O. tshawytscha*). Of the 383 active sites in Region X where in 2007 the index case of the infectious salmon anemia (ISA) outbreak occurred, 98 percent (375 sites) were farming Atlantic salmon (Halwart et al. 2007). By October 2011, the distribution of salmon farms operating in seawater per region had changed: 43 percent in Region X, 51 percent in Region XI and 5 percent in Region XII (SalmonChile, unpublished data).

Over the years, the composition of cultured salmon species also changed. In 1990, 59 percent of farmed salmon was Coho, 25 percent rainbow trout, and 16 percent Atlantic salmon. By 2006, this had changed to 63 percent Atlantic salmon, 20 percent Rainbow trout, and 17 percent Coho. In October 2011, Rainbow trout comprised 38 percent, Atlantic salmon 38 percent, and Coho 24 percent. These changes occurred partly because of market demand and, more recently, due to the ISA epidemic in Atlantic salmon.

Industry Associations

SalmonChile is a private sector organization that was created in 1986 to represent producers of salmon and trout in Chile. It provides a mechanism through which the industry has been able to:

- develop guidelines for food quality and safety,
- develop policies for fish health,
- interact with local communities,
- represent the industry to government and international organizations.

SalmonChile's 2012 membership included 28 companies producing salmon and trout, accounting for 67 percent of Chile's total salmonid productive capacity.

The technical arm of SalmonChile is the Salmon Technology Institute (INTESAL), responsible for technical coordination and monitoring of the industry in fish health, environmental

responsibility, food safety, and matters important for trade at national and international levels. SalmonChile funds INTESAL's research and development through a levy on salmon exports.

Trout and Coho Salmon Producers Association (ACOTRUCH) is a separate association that was formed in September 2009 to represent small- and medium-sized Coho salmon and trout producers in Chile. Some of these companies were previously members of SalmonChile and decided to regroup as ISA in Atlantic salmon became SalmonChile's main focus. Other companies remain independent of either of these associations.

Apart from these producer organizations, the suppliers are also organized in associations, the main ones being those representing the maritime services, divers, net services, pharmaceutical labs, and environmental labs. Even though the feed producers are the most important suppliers in terms of the industry's farming costs, they are not represented by an association.

Chilean Aquaculture Governance

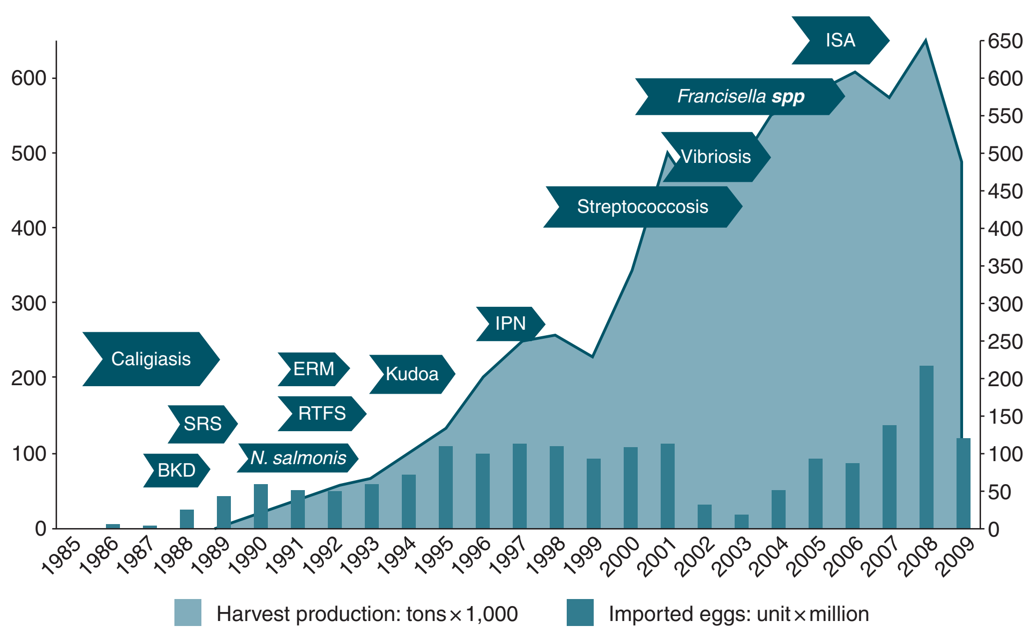
The management of the Chilean aquaculture industry is the responsibility of two government agencies:

1. The Undersecretariat of Fisheries, SUBPESCA in the Ministry of Economy, Development, and Tourism, is responsible for developing regulations and rules that govern aquatic animal resources in Chile in accordance with the General Law on Fisheries and Aquaculture (GLFA) No 18.892 and its subsequent amendments.[1] One of the objectives of SUBPESCA is to promote the sustainable development of fisheries and aquaculture.
2. The National Fisheries Service, Servicio Nacional de Pesca (SERNAPESCA), is also under the Ministry of Economy, Development, and Tourism. SERNAPESCA is responsible for overseeing compliance with the requirements and regulations issued by SUBPESCA.

Prior to the development of Chile's salmon farming industry, SUBPESCA's main focus was on the regulation of capture fisheries, and SERNAPESCA's main focus was the enforcement of capture fisheries regulations. Both agencies had few personnel with experience in aquaculture and fish health management. Since the development of salmon farming, however, SERNAPESCA has been given new responsibilities and has had to reorganize its departmental structure to reflect these changes in function, especially increasing inspection (SERNAPESCA 2009). Consequently, the agency's staff increased from 200 in 2007 to 729 in 2009, primarily in response to the ISA crisis and new government regulations. Most recently

1 http://www.subpesca.cl/controls/neochannels/neo_ch617/neochn617.aspx.: Full text and amendments of the GLFA (Ley General de Pesca y Acuicultura N° 20.560).

FIGURE 2.6: Timeline of Salmon Disease Occurrence, Production, and Egg Imports in Chile (C Barros unpublished)



GLFA No 20.434 (published in April 2010) created an Aquaculture Subdivision in SERNAPESCA and reinforced SUBPESCA's National Direction of Aquaculture. These two organizational changes were intended to strengthen the government's role in inspection and enforcement and distinguish aquaculture from fisheries.

Principal Health Issues Prior to ISA

Prior to the ISA crisis in Chile in 2007 several other infectious diseases were present in the industry. The first record of these is illustrated in figure 2.6 and compared to growth of production and egg imports.

The three primary fish diseases in the Chilean industry prior to 2007 were caligiasis caused by sea lice (*Caligus rogercresseyi*), Salmon Rickettsial Syndrome (SRS) caused by *Piscirickettsia salmonis*, and infectious pancreatic necrosis (IPN), caused by the pancreatic necrosis virus (IPNV). IPNV affects fish in both fresh and salt water, while the other two diseases occur only in salt water. In the past, the negative impact of these diseases on production was simply accepted and compensated for by increasing smolt numbers in grow-out cages. SRS, the most significant disease, has no effective vaccine, but is treatable and has thus led to high levels of antibiotic use. Interestingly and as expected, the disease control measures implemented due to ISA crisis have also decreased the number of SRS cases in the industry.

2.2 THE INFECTIOUS SALMON ANEMIA (ISA) CRISIS

The Virus (ISAV)

ISA is a serious viral disease of marine-farmed Atlantic salmon (*Salmo salar*) caused by the ISA virus (ISAV). Clinical signs of ISA include pale gills due to anemia, blood-tinged fluid in peritoneal and pericardial cavities, petechial hemorrhages of the viscera and parietal peritoneum, and dark red liver and spleen (OIE 2011).

ISAV belongs to the family *Orthomyxoviridae*, together with influenza viruses, but is sufficiently different to be assigned its own genus, Isavirus.

ISAV occurs in two basic genotypes (Kibenge et al. 2001a): North American (HPR) and European (EU). Further differentiation within these groups has been elucidated by Kibenge et al. (2007) and Nylund et al. (2007). ISAV highly polymorphic region (HPR0) is a nonpathogenic variant of ISAV that has emerged in all countries with a history of ISA. It is commonly associated with gill infections but does not cause mortality. It also does not grow in cell culture. Because this type of ISAV does not cause clinical disease and does not grow in cell culture, infections are not regarded as significant by the regulatory agencies. The role this virus plays in the epidemiology of ISA is not clearly understood (MacBeath et al. 2009; Debes et al. 2011).

ISA is arguably the most economically important viral disease of marine-farmed Atlantic salmon in terms of production losses, loss of export markets, and associated social impacts. Eradication of the disease and/or control of the viral infection have been priorities for the Atlantic salmon industry wherever the disease has occurred.

In the Northern hemisphere, the first registered outbreak of ISA was in 1984 in Atlantic salmon juveniles on the southwestern coast of Norway. The situation developed into an epidemic, which peaked with a total of 80 new cases in 1990. From 1989 to 1991, Norwegian authorities imposed a series of new biosecurity measures to try to control it, including:

- a ban on use of seawater in hatcheries.
- a ban on movement of fish from one seawater site to another.
- introduction of compulsory health certificates for aquaculture farms.
- disinfection of wastewater from processing plants and smolt transport.

Since 1994, the annual incidence of ISA outbreaks in Norway has varied between 2 and 23 (Norwegian Veterinary Institute 2013).

The disease was first reported outside of Norway in 1996, in New Brunswick, Canada. Subsequently, ISA was detected in Scotland in 1998, in the Faroe Islands in 1999, and in Maine, United States, in 2000. The virus was also detected in marine-farmed rainbow trout (*O. mykiss*) with subclinical disease in Ireland in 2002.

The Chilean ISA Index Case and the Crisis

Although ISAV had been detected in one group of Coho salmon that presented a disease named "Jaundice Coho Salmon Syndrome" in Chile in 1999 (Kibenge et al. 2001b), the virus had never been associated with ISA disease in the Southern hemisphere. During the winter (July) of 2007, unexplained mortalities following

recovery from an outbreak of SRS were observed in premarket (3.9 kg) Atlantic salmon at a grow-out site located in central Chiloé in Region X. This was the area in Chile where salmon production was most concentrated at the time. Subsequent investigation confirmed ISA in its classic presentation (Godoy et al. 2008).

However, this does not mean that the index case was the first time that Atlantic salmon had been infected with ISAV in Chile. Based on recent interviews with key individuals in the Chilean aquaculture industry, it is possible that ISAV had been present and causing health problems a few years before July 2007. INTESAL records suggested an increase in "nonidentified" causes of mortality starting around 2004, specifically in areas with a high number of farms.

There are several reasons for suspecting that ISAV may have been in Chile prior to 2007. First, the phylogenetic analysis by Kibenge et al. (2009) showed that the Chilean ISAV was genetically similar to ISAV reported in Norway in 1996.

Second, the virus found in the index case in Chile had more mutations than several other viruses isolated in subsequent cases, which suggests the origin of these other cases predated the virus found in the index case.

Third, consistent with this is the report that several fish farms in the same neighborhood as the index case were also experiencing high mortalities at the time. Many farms in the area attributed the increased mortalities to amoebic gill disease (AGD) and it is possible that coinfections with gill amoeba masked ISA mortalities. In addition, sea lice, a potential vector of ISA, was problematic toward the end of 2006 and beginning of 2007, particularly in the Reloncavi Gulf and Central Chiloé.

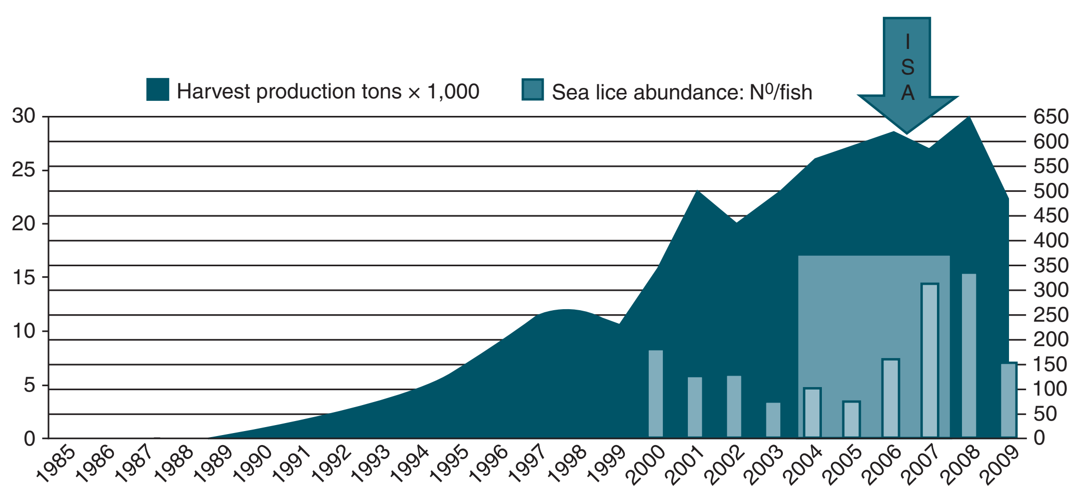
Fourth, according to sources in the Chilean aquaculture industry, for several years prior to 2007 laboratories had detected ISAV in Atlantic salmon[2] but these results were not reported because they could not be confirmed. Basically, it was said that diagnostic tests for ISAV in Chile prior to 2007 were not well developed or validated, although techniques applied in surveillance programs were those recommended by the World Organization for Animal Health (OIE).

If ISAV was present in Chile prior to 2007, the virus was not causing massive mortalities. It was with the increasing number of farms and fish density, high levels of sea lice starting around 2006, and weak biosecurity measures between 2004 and 2007 that permitted its dispersal (Stagg et al. 2001; Halwart et al. 2007). Although the precise time when ISAV was introduced to Chile remains a topic of debate, there is no question that in 2007, when the virus was officially detected, it spread rapidly throughout the industry.

The number of farms affected by ISA peaked at the end of 2008 (figure 2.7), but the economic impact of the crisis was not

2 The technique used then was virus isolation on cell culture in CHSE-214 cell line. As second option either EPC or BF-2 cell line.

FIGURE 2.7: Production and Sea Lice (Caligus) Infestation Immediately Prior to the ISA Outbreak (C Barros unpublished)



completely felt until 2009–10, when harvests and production were at their lowest. Production of Atlantic salmon dropped by about two-thirds due to ISA mortality and the culling of affected farms (Asche et al. 2009). Additionally, affected sites were not restocked with new Atlantic salmon smolts. Several companies attempted to compensate for these losses by raising rainbow trout and Coho salmon. It is remarkable that the total salmonids net production (tons) and exports (million US$) decreased from 2008 to 2010 by 33.3 percent and 29.6 percent, respectively.

The ISA virus crisis also had a significant social cost. It is estimated that 50 percent of direct and indirect job positions were lost, representing around 25,000 thousand workers. The last clinical outbreak was recorded September 2010 (SERNAPESCA 2010).

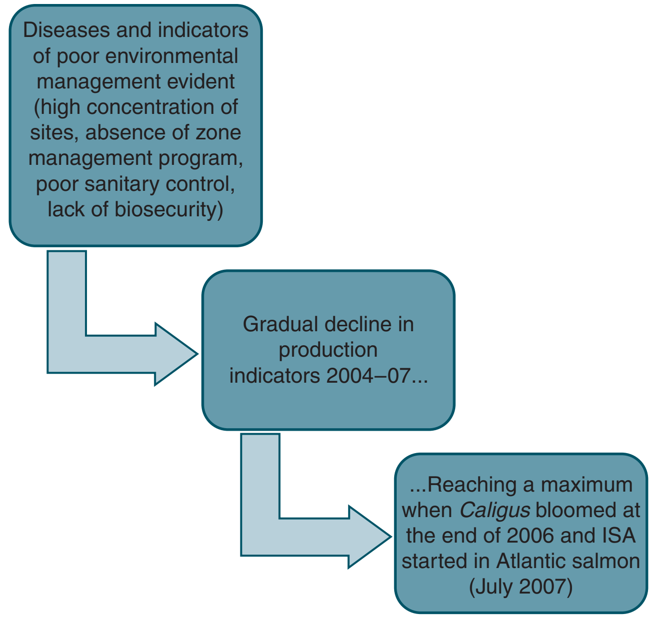
Conditions Leading up to the ISA Crisis and Spread of ISAV

There is consensus that the industry grew more rapidly than the government regulations could cope with. When salmon farming first started there were few regulations in place to control disease introduction and dispersion. The industry was performing so well economically with relatively few issues that no consideration was given to the limitation of the biological system. Several production indicators showed a gradual deterioration in Atlantic salmon performance from 2004, bottoming out between 2008 and 2009 (figure 2.8). Among the principal indicators and their observed deterioration are: harvest weight: 4.5 kg to 2.7 kg; productivity (harvested kg/planted smolt) 3.0 to 1.8; cumulative monthly mortality in seawater (in number of fish) 2 percent to 15 percent (Alvial 2011).

The industry was also growing and providing economic stability to an area that was historically deprived. Recognizing the economic and social benefits, the government implemented the National Aquaculture Policy in 2002 which aimed at doubling aquaculture production by 2012 with very few restrictions or consideration for environmental vigilance and disease control. This goal was reached early (in 2005), demonstrating how fast this industry was permitted to grow.

However, salmon farmers recognized that disease was an issue particularly in some areas where indicators of production had declined. In response, SalmonChile, through INTESAL, added fish

FIGURE 2.8: Poor Management and Decline of Productive Ratios Pre-ISA.



health and environmental vigilance systems to its sea lice and phytoplankton monitoring programs, as well as making a first attempt to define production zones in Chilean waters. Additionally, in 2003, the industry established a best practices system known as the Integrated Management System (SIGES) of the salmon industry, covering environment, fish health, food safety, and social aspects. All these efforts were voluntary. There was limited appreciation at the time of the biological risks that the industry was taking.

Basically, prior to 2007 the industry was enjoying high prices for its product and increasing production. In hindsight, it is easy to see where problems were occurring, but at the time there was reluctance to recognize them. Further, it is difficult to know whether the industry would have made changes even if they had been proposed by government. Rapid growth was the priority and costly long- and medium-term infectious disease prevention strategies were ignored. The general reaction was to stock more fish to compensate for losses due to disease mortality.

In hindsight, several management issues were evident:

1. There were high concentrations of sites in some farming areas, especially Region X and central Chiloé.
2. There was an absence of zone management programs.

3. There was poor sanitary control on farms including poorly regulated importation of fish eggs, no fallowing periods, and lack of disinfection procedures.
4. There was insufficient attention paid to biosecurity including frequent fish movement between farms.
5. There was a lack of comprehensive government regulations and control.

This resulted in a general increase in fish mortality, particularly in the major production areas. The cause of death was mostly undetermined, and there was an increase in the prevalence of the sea lice. The increase in sea lice infestation (as well as the increase in mortality from what looked like infectious causes) may have reflected a general overpopulation of susceptible fish in the area with minimal area-wide disease control measures in place.

The sea lice problem peaked at the beginning of 2007 with average farm abundance levels at 30 to 50 parasites per fish.[3] These high levels may have been exacerbated by the combination of favorable oceanographic conditions (increased salinity due to a period of low rain), the development of resistance to emamectine benzoate (the major therapeutant), and the generally poor condition of the fish as a result of crowding stress, skin damage, and coinfections with other pathogens.

Rapid spread of ISAV during outbreaks in the northern hemisphere has been associated with movement of virus in hauling water, live fish, and the use of contaminated equipment shared among fish farms. For example, ISAV has been transmitted from site to site by feed boats (McClure et al. 2005), by boats carrying fish, and in ballast water (Murray et al. 2002) via movement of infected fish (Stagg 2003), or through the water column due to proximity to other farms or processing plants with ISAV infected fish (Jarp and Karlsen 1997).

Mardones et al. (2009) investigated the epidemiology of ISAV during the first year of the outbreak in Region X and reported both the clustering of cases as well as long-distance dispersion of the virus, suggesting multiple routes of transmission. In Chile, all of these routes of transmission were uncontrolled in 2007 and certainly led to the dissemination of the virus:

3 Compare this to the 0.5 sea lice per fish threshold for therapy under Norwegian regulations.

- Smolts were not screened for health status, so weak and sickly fish were often stocked. The incentive to increase production was stronger than the incentive to assure good fish performance.
- Smoltification was often completed in estuaries where all three species and different age groups shared the same body of water. If disease was present in this area it easily spread throughout the industry with the transfer of smolts to grow-out sites.
- High stocking numbers on farms (>1.5 million fish) and high densities of fish in individual cages (25 to 30 kg/m^3), resulted in high levels of virus being released from a farm once it was infected with ISAV.
- Close proximity of farms in some areas. Approximately 40 percent of Chile's total salmon production in 2007 was concentrated in the central and east coasts of Chiloé Island, which increased the likelihood of easy and rapid spread of disease.
- Close proximity of farms to processing plants (<5 km). The OIE suggests sites within 5 km of an infected farm or a processing plant harvesting infected fish are at high risk of acquiring the disease. Mardones et al. (2011) suggest that 10 km may be a more appropriate infection zone based on their evaluation of the Chilean epidemic, the number of fish on a site at the time of infection being a determining factor in the size of the zone needed to contain disease.
- Mortality management did not consider pathogen inactivation and containers in which mortalities were transported were not adequately secured to avoid spillage or theft.
- Harvest systems that could not cope with the increased demand created by the elimination of infected fish. As the number of outbreaks increased, prices rose, putting more upward pressure on stocking rates.
- Effluent disinfection at processing plants was not practiced in 2007.
- Unrestricted and extensive movement of fish and personnel between farms. Sharing of equipment (nets, boats, barges, and so forth) among farms and lack of disinfection and/or oversight of cleaning.
- Use of "open" well boats to transport fish between farms, which means that water containing the virus would have been released along the vessel's entire route
- There was no mandatory "break" between year classes of fish on a farm (that is, fallow periods were voluntary).
- High sea lice levels most likely caused by the increase in active farms in Region X. Sea lice are known to move between

farms in close proximity and can carry ISAV. Wild fish, such as Robalo (*Eleginops maclovinus*) infested with sea lice may also have spread ISAV between farms.

- Prior to 2007, there was insufficient surveillance for diseases on salmon farms and inadequate diagnostic laboratory capacity to detect health problems early in a disease outbreak. Single agent diagnostic assays such as singleplex polymerase chain reaction/reverse transcription-polymerase chain reaction (PCR/RT-PCR) that are used for pathogen surveillance/screening programs are severely limited since they are based on known pathogen nucleic acid sequence information. These assays are good in a characteristic disease outbreak or in situations suggestive of infection with a known pathogen but are not ideal in the absence of clinical signs or in situations where a particular disease is not known to occur, such as ISA in Chile prior to June 2007.
- Long lag time between the diagnosis of ISAV and the harvest or elimination of infected fish, which meant that infected farms served as reservoirs of infection. During the crisis, SERNAPESCA estimated that on average it took 90 and 130 days for elimination or harvest of fish, respectively (Mardones et al. 2009).
- Inadequate awareness by senior management in companies of the problem as it was developing.

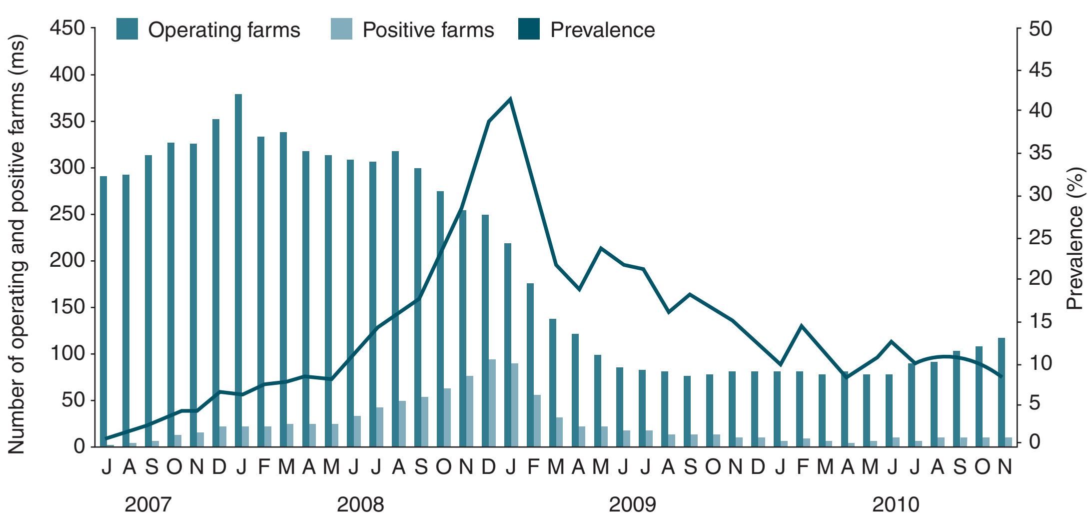
In summary, there were many conditions that favored the spread and potential outbreak of infectious pathogens in July 2007, as it finally happened (figure 2.9).

Possible Sources of ISAV

The evidence suggests that the ISAV that caused the ISA outbreak in Atlantic salmon in Chile originated in Norway. The ISAV in the first outbreak in June 2007 was most similar to isolates from Norway (Kibenge et al. 2009; Vike et al. 2009; Cottet et al. 2010). The phylogenetic analysis of Kibenge et al. (2009) showed that the Chilean ISAV was genetically unique, although similar to ISAV isolates reported in Norway in 1996.

How ISAV entered into Chile is still being debated. A study by Vike et al. (2009) suggested that the virus was introduced to Chile through fish egg imports from Norway over the past 10 years. Fish egg imports started to rise from 1985 with increasing aquaculture production (figure 2.6); there was a significant jump in 1995 when it reached 100 million units and remained at this level until 2001. There was a drop in 2002 and 2003, but imports returned to 100 million units in 2005, and peaked at >200 million units in 2008 at the peak of the ISA crisis (Asche et al. 2009). Although there were some restrictions on egg imports (that is, they had to originate from ISAV negative farms), the regulations were weak and insufficient. It would have been difficult for SERNAPESCA to enforce these regulations on all imports with the limited number of personnel they had prior to 2008.

FIGURE 2.9: Number of Operating Atlantic Salmon Farms (blue bars), ISA Positive Farms (red bars), and ISA Prevalence (green line) from July 2007 to November 2010 (SERNAPESCA 2010)



If imported eggs were the source of the infection, it would most likely have been through pseudovertical transmission, that is, virus contaminating the egg surfaces or fluids, which can normally be controlled through disinfection. True vertical transmission of ISAV has not been reproduced experimentally (Melville and Griffiths 1999), and there has been no evidence of true vertical transmission of ISAV in New Brunswick, Maine, and Faroe Islands. In Norway, only 0.7 percent of ISA outbreaks occurred in the freshwater stage (that is, eggs and juveniles). Export of eggs from an infected farm in Norway to Iceland in 1986-87 did not lead to ISA in Iceland. An extensive review by a special scientific committee in Norway concluded that true vertical transmission of ISAV, if it occurs, is of little significance (Rimstad et al. 2006). A report sponsored by the European Commission on the issue of trading of fish eggs concluded that vertical transmission was insignificant in the epidemiology of ISAV infection (Bovo et al. 2005).

2.3 MEASURES TAKEN IN RESPONSE TO THE ISA CRISIS

The Crucial Approach

One of the most impressive and crucial aspects of the Chilean ISA recovery was the collaboration between the industry and government to construct a platform for addressing the problem, from both short-term and long term perspectives. After the declaration of the index case, a partnership was established between the government and the industry, which permitted companies, particularly those having previous experience with ISA control, to make technical contributions to the initial emergency containment and contingency plans. Later, the government established "La Mesa del Salmon" (Salmon Committee) where all involved public sector agencies were represented and consulted regarding proposed major regulatory changes.

This response by government and industry, which targeted the factors most likely to be contributing to the spread of the virus, resulted in the control of the disease within 3½ years. The measures taken can be divided between those that were expected to have immediate effects and those whose benefits would be seen in the longer term (SalmonChile 2009).

Rapid Measures Taken with Immediate Effect

Less than 1 month after the first ISA case, the industry established the first voluntary agreements and initiated a series of collaborative actions to avoid the dispersion of ISAV and improve detection and depopulation of infected sites. There were many meetings between companies and SalmonChile to establish these first measures.

In addition, 3 months after the diagnosis of the index case, INTESAL and partners organized an international workshop to provide government and the industry with suggestions on monitoring, detection techniques, control measures, and regulation/enforcement tools. This workshop helped the government and INTESAL establish the first set of control measures for ISA. This initiative was repeated 1 year later, bringing more information and experience to the country.

INTESAL led industry efforts to establish good practices to control sea lice and ISA, which were perceived to be related. Independent of the government they developed the Salmon Industry Health Policy, which had five objectives and contained 44 measures to control and prevent disease and ensure sustainable growth of the salmon industry. This policy was supported by all the associated companies and was regularly reviewed and audited. Most of the 44 measures were integrated into formal regulation by the government several months later.

Three of the five objectives of the health policy specifically addressed pathogen spread: (a) to reduce the likelihood of perpetuating fish pathogens within the industry; (b) to minimize the risk of introducing exotic pathogens via the importation of eggs; and (c) to ensure the production of healthy smolts and minimize pathogen transfer from freshwater facilities. To achieve these objectives, the industry designed a list of recommended management practices in 10 parts covering all sectors of the industry. These were to be implemented within a 5-year period by the members of SalmonChile, beginning in 2009. Currently, about 90 percent of these measures have been implemented, and most agree that the top seven measures responsible for the recovery are:

1. All in/all out farming with fallowing periods and zone management
2. Restriction of fish movements

3. Coordination of sea lice control
4. Vaccination
5. The use of good quality smolts
6. Reduction of farm stocking numbers (total biomass)
7. Better surveillance and better diagnostic capacities

Other measures included:

- Decreased use of lakes and transient estuary sites where mixed species culture and holding increases the risk of pathogen dissemination
- Proper inactivation of pathogens in dead fish
- Freshwater-only rearing of Atlantic salmon broodstock
- Weekly sea lice monitoring and treatment when average abundance equals three adult lice per fish
- Two disinfections for eggs
- Single species at all sites
- Biosecurity protocols for visitors and farm staff
- All sites must be fallowed in a coordinated way after a 24-month period.

The voluntary industry measures are audited by SalmonChile to ensure compliance, and company CEOs meet monthly to discuss implementation. As was mentioned above, many of these measures have since been incorporated in government regulations, which apply to the entire salmon industry.

Two months after the first case of ISA was detected the government enacted a contingency plan to control ISA, and shortly afterward a plan to control sea lice. These plans were based on an intensive collaboration with foreign institutions and companies who had experience dealing with these diseases, and targeted preventing and controlling the spread of infectious disease. Also, SERNAPESCA increased its inspection capacity by reallocating resources and meeting frequently with the industry. These government measures were aimed at:

1. Reducing the spread of ISAV and sea lice between farms by identifying and eliminating cases early in the disease process and preventing the introduction of the virus to uninfected sites.
2. Reducing the likelihood of introducing ISAV from foreign sources.
3. Early detection through increased surveillance and mandatory removal of infected fish to prevent the spread to other farms.

These immediate measures taken by the government in 2007–08 intensified biosecurity on farms, quality assurance of diagnostic laboratories, and mandatory reporting of ISA cases (detailed in box 2.1).

In addition to the fish health measures implemented by the industry and enforced by the government (boxes 2.2 and 2.3), several other changes were introduced by the salmon producers themselves:

- A reduction in the number of fish on farms (from an average of 1.2 million to approximately 800,000). This reduced the number of cages used on a normal farm to between 18 and 20 and put a cap on rearing densities of 17 kg/m^3 lowering

BOX 2.1: Mandatory Reporting

ORIGINAL MEASURES:
One of the principal elements of the "Specific Sanitary Program of ISA Control and Surveillance" was the reporting of suspected or confirmed cases of ISA to SERNAPESCA:
Mandatory reporting: salmon farms must report immediately to SERNAPESCA any detection or reasonable suspicion of ISAV. The notification should be sent to notificacionisa@sernapesca.cl. Also, farms must send an epidemiological survey plan (www.sernapesca.cl) within 48 hours after the notification. Any person that has information about a suspicion of the presence of ISA or unexplainable mortalities should notify notificacionisa@sernapesca.cl.
Diagnostic and references laboratories: any laboratory that suspects or has diagnosed ISA in official or private monitoring must immediately notify SERNAPESCA. The notification should be sent to diagnosticoisa@sernapesca.cl.
REGULATION IMPROVEMENT:
- Independent auditing of labs and farms.
- Surveillance to include increased sampling of wild fish in both fresh- and seawater.
- Increased sanctions for individuals that violate regulations.
- Increased capacity and power of SERNAPESCA to monitoring sanitary measures and other regulations.
- Restriction of smoltification of Atlantic salmon in lakes and estuaries to prevent mixing of populations.
- All information on ISAV test results are made available to the public.

the amount of virus produced by infected farms and reducing the infectious zone around these farms.

- There was a change in the species farmed from predominantly Atlantic salmon to Coho and trout. Rainbow trout and Coho salmon are not as susceptible to the ISA disease as Atlantic salmon (Rolland & Winton 2003). Mardones et al. (2011) recently reported that within Region X, ISAV was reported in 4/80 (5.0 percent) trout farms, and in Region XI

BOX 2.2: A Summary of the Immediate Measures Taken by the Government (2007–08).

Implementation of an ISAV surveillance program including:

- Site visits every 3 months to all salmonid farms and more frequently for farms in close proximity to any virus positive farm.
- Mandatory testing of 30 fish from each farm, at least every 3 months with sampling biased toward selection of weaker fish.
- Individual testing of all broodstock (screening broodstock for ISAV and disinfecting eggs was effective in eliminating ISAV in freshwater facilities after 2008).
- Mandatory reporting (see box 1.1).
- Regular surveillance of wild fish in fresh and salt water.

Implementation of an ISAV control program that:

- Establishes specific biosecurity protocols for fish harvest, transport, and effluent disinfection at processing plants (see box 1.3).
- Requires all farms with ISAV to cull fish according to its prevalence.
- Requires all farms with ISAV to eliminate or harvest their fish in a manner that contains or treats effluent liquid waste.
- Requires quarantine for ISAV positive farms and those in close proximity to ISAV until infected fish are removed.
- Requires all farms in an infected zone be placed under increased surveillance.

Implementation of a sea lice surveillance and control program that:

- Requires farmers to report sea lice levels biweekly.
- Requires farmers to treat sea lice when average abundance exceeds six adult lice per fish.
- Improved sea lice management by permitting the use of three new drugs.

BOX 2.3: Biosecurity and Sanitary Regulations Adopted by the Chilean Authorities

- Testing of fish for List 1 and List 2* pathogens within 15 days of any fish movement
- A ban on movement of smolts from potentially infected zones to zones thought to be free of infection (all diseases)
- Requirement that a designated fish health professional be appointed for each company
- All-in all-out stocking, that is no mixing of separate year classes. Fish stocking at a site is to be completed within a 3-month period
- Mandatory fallowing between year classes
- Designation of neighborhood zones, with coordinated fallowing within zones
- Minimum distance between salmonid farms of 1.5 nautical miles
- Minimum distance between processing plants and farms of 1.5 nautical miles
- No sharing of day-to-day equipment between saltwater farms; mandatory disinfection of larger equipment that is shared among farms
- Regulation of net cleaning operations
- No movement of fish after stocking for grow-out
- Daily removal and proper disposal of dead fish
- Regulation of fish density in cages
- Containment of liquid waste during harvest and treatment before disposal
- Treatment of effluent water during transport for fish known to be infected with ISAV
- Reinforcement and control of all eggs' disinfection
- No importation of eggs from countries with ISAV or pancreas disease
- Mandatory disinfection of all processing plant effluents receiving fish from a quarantine area (since 2009)

* High-risk diseases are classified as List 1 or 2, depending upon their virulence, prevalence, distribution, and economic importance. List 1 are those high-risk diseases that have to be declared to OIE or those which have not been detected before in the national territory or those with distribution restricted to some defined areas in the country. List 2 includes the rest of the diseases.

in 1/48 (2.1 percent) trout farms. However, because it is difficult to detect ISAV in these carrier fish species, especially in the case of trout, they may contribute to making the virus endemic (Rolland and Winton 2003; Kibenge et al. 2006; Biacchesi et al. 2007; MacWilliams et al. 2007).

- There was a reduction in the number of Atlantic salmon farming sites from 375 in 2007 to approximately 66 in 2009.
- As a result of using fewer saltwater leases, companies could be more selective in the sites they used. The industry now considers site selection one of the most important factors for reducing the risk of infectious diseases due to proximity to their neighbors. Some companies are even applying risk analysis systems to define priorities in terms of the sites to be stocked.
- There was a reduction in the demand for Atlantic salmon smolts (due to the reduced number of active saltwater sites), which reduced the demand on freshwater facilities and may have resulted in the elimination of poor quality fish at the freshwater life stage prior to saltwater transfer.
- The use of good quality smolts may have improved resistance to several pathogens.
- The industry also realized that introducing larger smolts on saltwater sites decreased the time in salt water and the risk associated with this life stage.
- Some companies eliminated ISA infected fish more quickly because they had capacity in their processing plants due to the significant decrease in overall production.
- As the demand for diagnostic tests increased, the capacity and quality of the private diagnostic laboratory facilities improved. This increased the sensitivity and speed for detecting virus.

In addition to actions taken by the government, industry, and companies that helped to reduce the spread of ISAV between farms, there were also key characteristics of ISAV that helped the control of this virus in the relatively short period of time.

- True vertical transmission of the virus through egg contents is limited, if it exists at all, so egg disinfection and the elimination of infected broodstock is likely an effective method of preventing the spread of the pathogen from parent to progeny.
- It is possible that the nonvirulent form of ISAV (ISAV HPR0) which is now endemic in Chile may be providing some level of herd immunity against the virulent forms of ISAV. In all regions where ISA has occurred in the world, including Norway, New Brunswick (Canada), Maine (United States), Scotland, and the Faroe Islands, the non-virulent strain of the virus has become the predominant genotype.

Measures Taken with Long-Term Effect (box 2.4)

By financing the growth of most of the major salmon farming companies in Chile, banks played a critical role in the industry expansion that preceded the ISA epidemic. At the heart of the crisis in 2009, it was estimated that salmon farming companies and their suppliers owed the banks a cumulative total of US$4 billion (Murias 2009). Cumulative debt of the farming companies was about half of this and individual companies were indebted in amounts up to US$380 million. Clearly, without access to this financing, the industry would not have been able to expand as it did.

As the full impact of the ISAV epidemic became apparent early in 2009, the banks had to decide whether to cut their losses by forcing companies into bankruptcy or to continue to support them by renegotiating loans. Advised by a valuation model of the 10 largest indebted companies generated by Claro y Asociados, they chose the latter course.

A key consideration in this decision was the understanding of, and belief in, the underlying premise of salmon farming as a business:

BOX 2.4: Essential Changes with Long-Term Effect

- New licenses are now for 25 years and may be relocated under circumstances of responsible management
- Licenses can be terminated if there are repeated environmental issues
- Zoning based on biological carrying capacity require strategic fallowings to limit disease spread and ensure environmental quality
- Improved annual environmental assessment of sediments and benthos contracted by the government but paid by the industry
- SERNAPESCA strictly controls mandatory reporting of ISAV and other diseases

- increasing global demand for seafood, which natural fisheries can no longer meet.
- the established importance of farmed salmon and trout in markets.
- excellent salmonid farming conditions in Chile.
- that salmon farming in other countries has recovered from ISA.

Therefore, it was likely that the Chilean salmon farming industry would also recover and the value of the companies and their assets would be restored. Though not without risk, loan renegotiation rather than asset seizure and bankruptcy seemed to be the best course; and this decision has proven correct and fundamental to the industry's recovery. For this, the banks and those who advised them deserve much credit. Their insight, patience and disinclination to panic serves as a model for new aquaculture industries elsewhere that might one day find themselves in a similar position.

The banks rejected the idea of any debt forgiveness and proceeded over a period of several months to renegotiate loans with each indebted company. This is documented in news reports published during this time in Chilean business newspapers and on the website www.FIS.com. Loan terms were extended, grace periods were granted on debt repayment, interest rates were reset and collateral was strengthened as companies were required to pledge more of their assets.

An especially important part of the collateral negotiations was the passing of modifications to the GLFA, which granted perpetual property rights to aquaculture concessions.[4] Through the Banks and Financial Institution Association (ABIF), the banks urged the Chilean Senate in June 2009 to pass this measure as a matter of urgency without which they argued "a good proportion of producer firms" will disappear along with supplier companies. They pointed out that the passing of this measure would also serve as a mortgage guarantee to activate a US$450 million line of credit to which the Chilean government had pledged 60 percent in collateral (A Murias, personal communication).

4 These differ from operating licenses (see below), which are temporary but have been extended up to 25 years.

Loan renegotiations were conducted with each company by one lead bank on behalf of all lenders. In addition to changes in repayment, interest, and collateral terms, lenders also required that a bank observer be placed with each company to ensure financial propriety and that the companies must comply with new sanitary rules established in the Law and those developed by INTESAL.

Not only did the banks demand acceptance of these new rules through covenants in the revised loan terms, but together with INTESAL and the government they helped to fund a monitoring program to audit the salmon farmers' compliance. This program ran through August 2012 and endorsed the ongoing implementation of new Aquaculture Biosecurity Regulation (RESA) rules as critical needs of the industry (Corniola 2010).

Finally, as the salmon farming companies' prospects recovered early in 2011 and it appeared that the worst of the ISA crisis had passed, there was an opportunity for companies to try to raise new capital through public share offerings. The money raised would allow them to pay down debt and/or to finance new inventory and capital improvements demanded by the new RESA rules (SUBPESCA 2011: Decree 349). The opportunity seemed especially good because of a generally positive mood in financial markets at the time together with increasing prices for farmed salmon. Several salmon farming companies who went to the market early in 2011 were successful. However, later in 2011, as global financial confidence ebbed and salmon prices declined, prospects for raising new capital diminished. At least one company delayed its stock market debut due to unfavorable market conditions (A Murias, personal communication).

In addition to the immediate disease control programs the Chilean government also formed "La mesa del salmon" (the Salmon Board). This group, comprising several branches of government was charged with further evaluation of potentially risky industry practices, and to propose new laws and regulations to respond to these challenges.

Also they evaluated the experience of other countries facing similar problems and visited and interviewed all stakeholders connected with the aquaculture industry to obtain their perspectives and aspirations. Universities, research groups, and nongovernmental organizations (NGOs) were also invited to give their views

on the proposed changes and needs for organization, research, and infrastructure.

As a result of the Salmon Board initiative a panel of experts was established to make recommendations on scientific and technical matters relating to industry practices. There have subsequently been a number of modifications to the Fishery and Aquaculture Law and related regulations. Recent (2011) specific modifications to the law that directly affect disease control include:

New licensing regime

New operating licenses will not be issued for an indefinite time. They are granted for specific periods of time and subject to strict compliance with environmental and labor laws. Violation of regulations will lead to the termination of the lease permit. Some licensees that are in compliance with lease requirements may relocate, subject to certain conditions, which may enable a reduction of, and thus better coordination among, companies operating in a particular zone under new area management regimes.

Area management regime

This is a system developed from the establishment of environmental zones that allows for more effective management of health and productivity within a defined area. Area management has permitted coordination of fallow and harvesting periods as well as treatments for disease and parasite infestations, improving environmental and sanitary status.

Improvement and control of environmental indicators

The government has set standards for the reduction of escapes of fish from farming systems and audits farms against these standards to ensure compliance. The government also established more rigorous environmental parameters that must be measured and met to ensure environmental sustainability.

Biosecurity throughout the value chain

There are numerous independent stakeholders throughout the salmon aquaculture value chain, and it was necessary to work with these to ensure that all practices throughout the production process are conducted in a responsible manner. The government took steps to regulate auxiliary industries that could have an effect on fish health (for example,, net cleaning, disinfection harvest practices, boat traffic between farms, inter alia).

Public access to industry information

Because it was recognized that good stewardship was an issue prior to and during the ISA crisis, the Salmon Board established a mechanism by which production and health information from farms was available to individuals in the industry and also reported to the general public. This was done to facilitate cooperation between neighbors regarding disease control and prevention as well as to encourage industry transparency.

2.4 THE RECOVERY AND OUTLOOK FOR THE FUTURE

Gradual Recovery along the Value Chain

Implementation of the new regulations and voluntary agreements described above have clearly impacted the industry in a favorable way in the short term and have established the basis for better performance in the long term. The effects of the changes were first apparent in seawater production in the second part of 2009 when several companies started experiencing lower mortalities and improved growth rates. These changes have also led to a much improved perception of the industry among investors and the banks, which in turn has meant that capital to finance renewed growth of the industry has been available.

It is now generally accepted that the recovery of the Chilean salmon industry started in 2011 and the volume of Atlantic salmon harvested will reach its pre-outbreak level (Asche et al. 2009) sometime between 2013 and 2015 (figure 2.10). Evidence of the recovery can be found in several performance indicators as described below.

It is noteworthy that in November 2011 SalmonChile reported that the distribution per species of fish stocked in seawater was 58 percent Atlantic salmon, 24 percent Rainbow trout, and 16 percent Coho salmon, revealing the industry's confidence in the recovery of Atlantic salmon production.

Improvement in fish performance has been especially good in Atlantic salmon, though advances have also been observed in the other two species. Control of sea lice and ISAV and the associated decreases in

FIGURE 2.10: Evolution of Salmonid Production in Chile and Projections for the Recovery (red bars) (O Gárate unpublished)

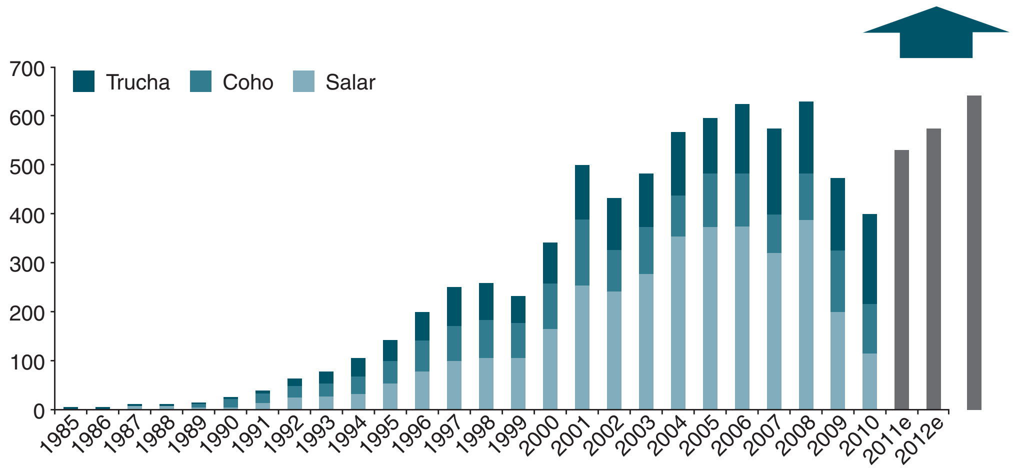


FIGURE 2.11: Average Sea Lice Load per Fish (a), ISA Confirmed Sites per Quarter (b) and Monthly Mortality for the 3 Salmonid Species (c) over the Course of the ISA Outbreak and Recovery (Alvial 2011)

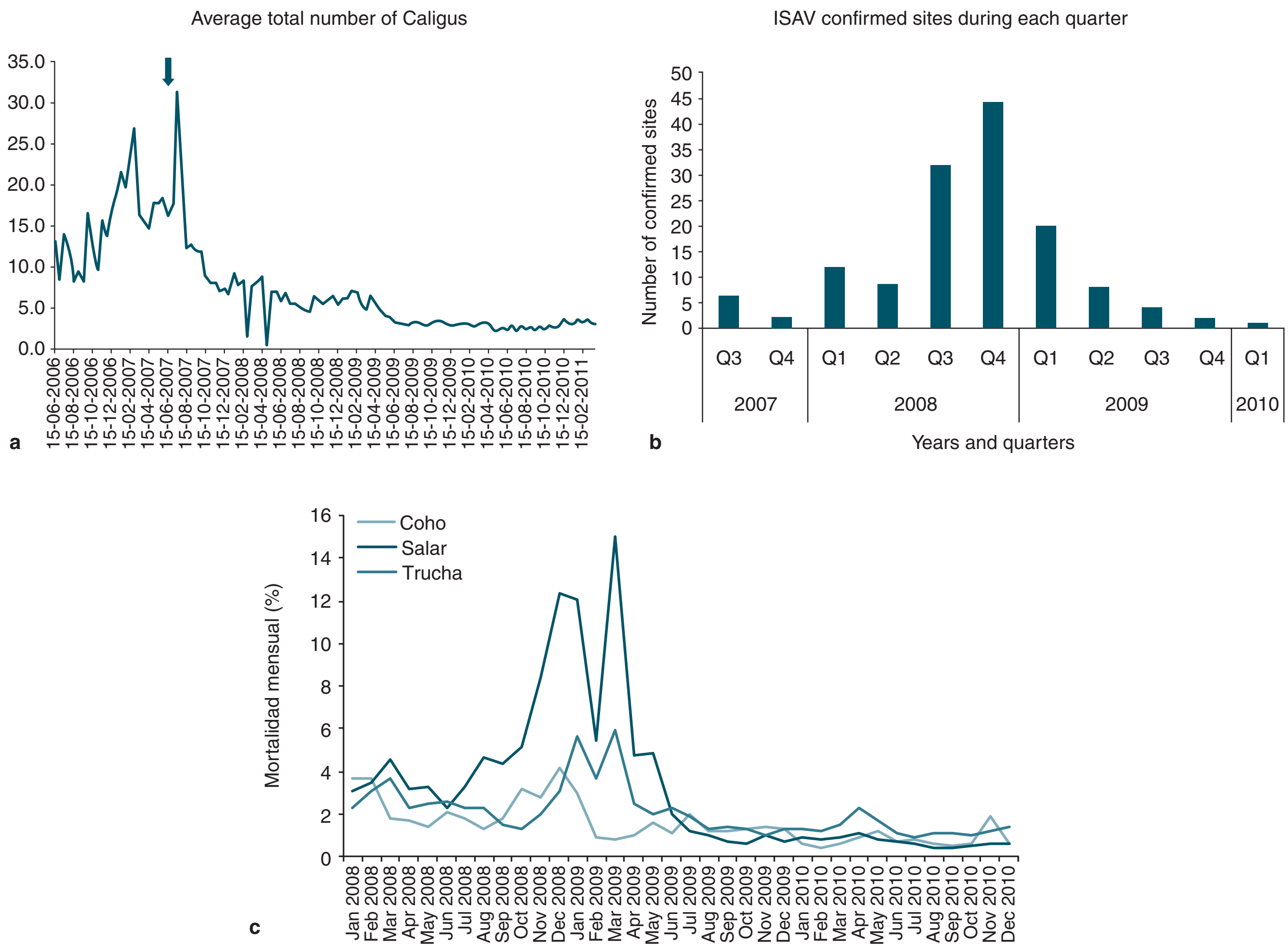


FIGURE 2.12: Accumulated Growth Rates for Atlantic Salmon Groups Harvested in 2008–10, Expressed as SGR (a) and GF3 (b) (Alvial 2011)

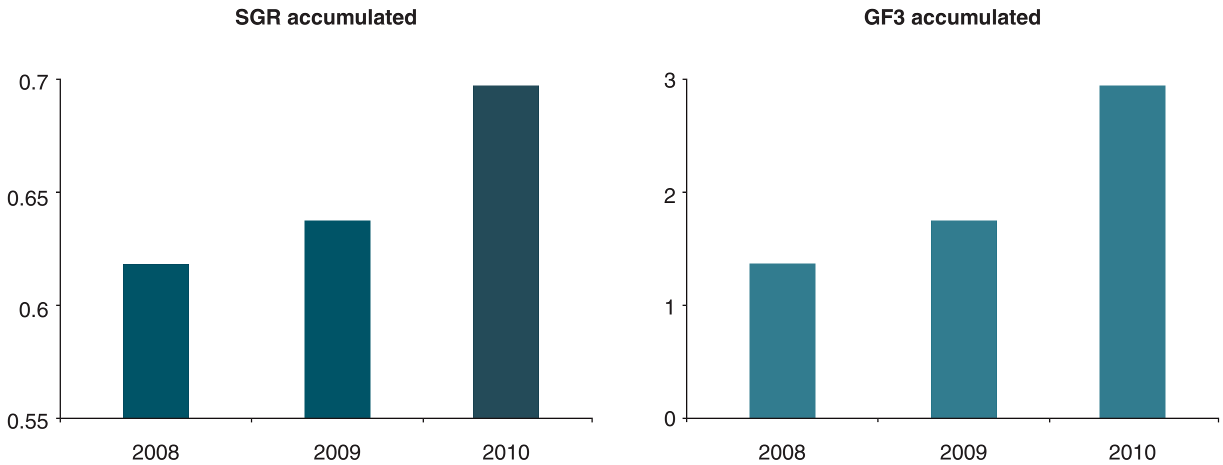
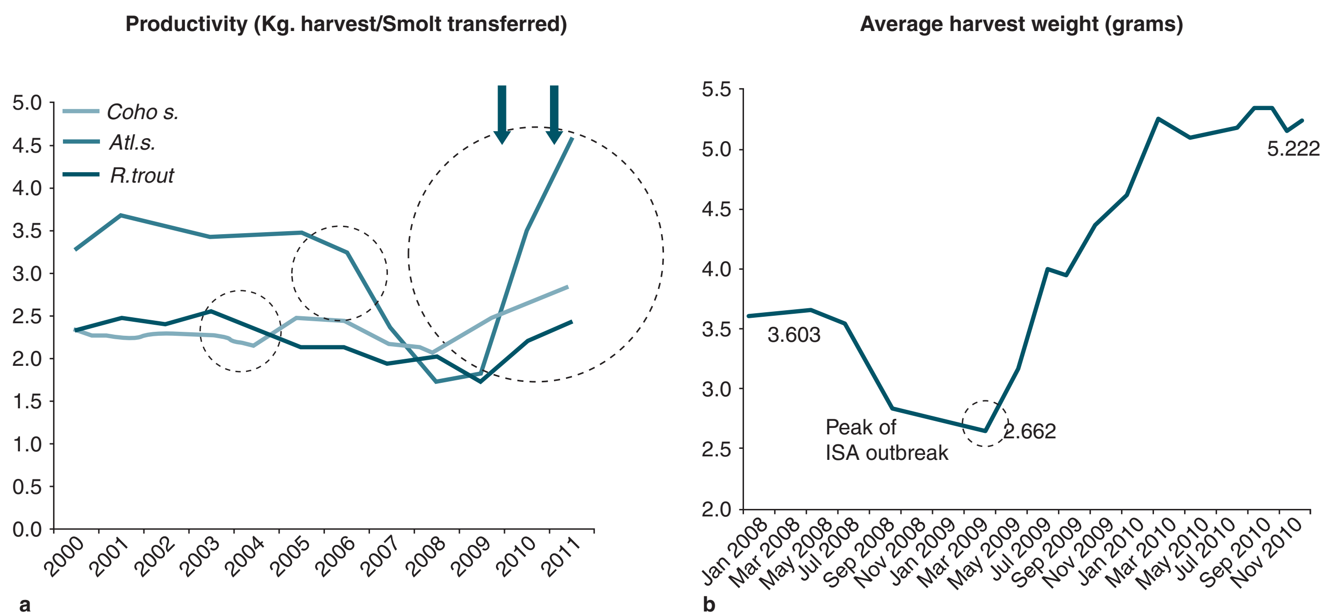


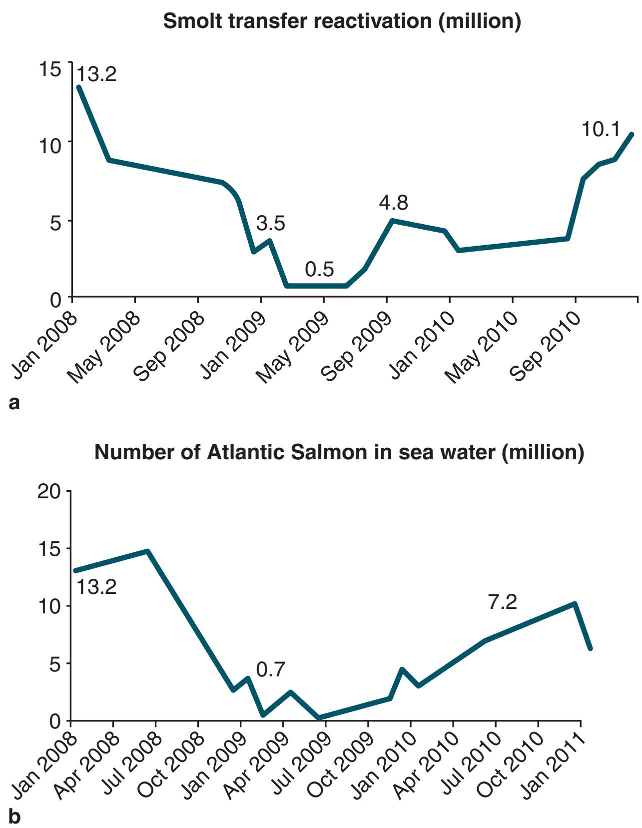
FIGURE 2.13: Productivity in Terms of Kilograms Harvested per Smolt Stocked (a) and Average Harvest Weight (b) of Atlantic Salmon, Pre- and Post-ISA crisis (Alvial 2011)



mortality are shown in figure 2.11. Improved growth for groups harvested between 2008 to 2010 is shown in figure 2.12, which led to an increase in the kilograms produced per smolt stocked (figure 2.13a), and increased average weight of fish harvested (figure 2.13b). These indicators of farm performance have now surpassed pre-ISA levels, suggesting better management throughout the production cycle. In turn, this better performance has led to an increase in Atlantic salmon smolts stocked as shown in figure 2.14.

Antibiotic use indicates problems with bacterial pathogens. The major bacterial pathogens for the Chilean salmon industry are *Piscirickettsia salmonis* (SRS), *Aeromonas salmonicida* (furunculosis), *Vibrio anguillarum* (vibriosis), and *Streptococcus phocae* (streptococcosis). Another good indicator of better biosecurity performance is the observed reduction in the use of antibiotics on Chilean salmon farms. A number of companies have completely excluded antibiotics on all or part or their operations.

FIGURE 2.14: Atlantic Salmon Smolt Transfer into Seawater per Month (a) and Number of Fish in Seawater (b), Pre- and Post-Crisis (Alvial 2011)



Though no generic industry data is available presently, these performance improvements are also likely to have led to lower production costs, especially lower feed costs due to better food conversion rates. Some companies have estimated cost savings up to 30 percent. In turn, this means less waste production per kg of fish produced resulting in better environmental performance. Of course, these cost savings have been achieved as a result of stricter biosecurity measures, which increased other costs, estimates ranging between 20 to 25 percent. Whether or not cost savings due to better fish performance offset this increase remains to be documented and it would helpful to both industry and government if this were done.

Outlook for Production

The environmental indicators used to assess whether an aquaculture farm is operating within the biological capacity of its location include good water quality reflected in levels of dissolved oxygen at or near saturation, and healthy benthic conditions (that is, toxic conditions in the first 2 or 3 cm, normal biodiversity and low hydrogen sulphide levels). These parameters are monitored by government according to the clauses established in the Environmental Regulation for Aquaculture (RAMA), which was modified in 2010 to include new regulations that strengthened the evaluation of benthic sediments under farm concessions. Further, all environmental monitoring now must be conducted by an independent entity approved and contracted by the authority. Farms are required to meet the minimum standards, otherwise sanctions are imposed.

The limits on pen density and enforced fallowing will result in a reduction in waste buildup in the environment, but with these new laws will come likely changes in the industry structure with companies that can absorb the cost of the new regulations doing better than those that cannot. Companies with more concessions (operating licenses) are also likely to have opportunities created by wider geographical diversification, while smaller companies may find themselves restricted by new neighborhood rules and may need to merge or exchange licenses.

Optimism within the salmon industry is high, with recovery under the new regulatory regime predicted within the next few years (Asche et al. 2009). In addition, the sustainable production level with better biosecurity is expected to approach 700,000 tons. Any production beyond this will require expanding the geographic farming area, most probably into Region XII.

The numbers of operating salmonid farms in October 2011 was 390 (Ansoleaga 2011) with over 1,041 operating licenses (SERNAPESCA 2009). Consolidation of licenses, allowed by the new regulations, will favor sustainability of the industry as it will allow better environmental management. Relocation of sites from Region X to Regions XI and XII will also enable a better balance in the use of Chile's coastal zone. At present, the government is supporting studies to establish the dominant hydrodynamic characteristics of the regions on the basis of which it can then estimate carrying capacity of proposed salmon sea farming zones. There is general agreement that precautionary measures should be applied until sufficient information on the

carrying capacity and dynamics of the areas is available, though smaller companies are less receptive than larger ones in regard to limiting biomass.

The much improved fish performance, as well as notable market strength early in 2011, has encouraged visions of expansion beyond precrisis levels. Ambitions go as high as 1.5 million tons (Eposito 2011) with annual sales of US$5 billion per year. If that happens, it will mark a new chapter in the development of salmon farming in Chile and it will call for care and discipline by all involved if the industry is not to expose itself to the risk of another disease epidemic.

Regional Social and Economic Impacts

The ISA crisis highlighted the strong dependency of the economies of Regions X and XI on the salmon farming industry. The first impacts were seen at the seawater farms where a reduction of workers was necessary due to the closure of many farms that focused too heavily on Atlantic salmon. This was followed by the reduction or closure of several hatcheries. However, in terms of laid-off workers the most significant impact occurred in the middle of 2008 when several processing plants, which were labor intensive, had to lay off their people.

The industry recovery described above stimulated a gradual reactivation of the industry starting in the second half of 2009. First, freshwater facilities had to begin producing smolts to be stocked in the sea given the better sanitary/environmental conditions. Then, starting in 2010 additional people were required for reactivated seawater operations continuing through 2011 with partial or total reopening of the processing plants.

Consequently, unemployment rates have come down (figure 2.15) while the Economic Activity Index of Regions X and XI has rebounded (figure 2.16). This steady growth in employment has, once again, positioned these regions among those with the lowest unemployment in Chile and reemphasized the vital importance of salmon farming to these regional economies.

A government program to improve port facilities and roads for the industry's long-term development also created more jobs, particularly in the Chiloé zone. The government has established the National Promotion and Innovation Agency (CORFO), a subsidiary plan to cofinance initiatives to improve the environmental/sanitary situation of the industry through innovation.

Also, a number of foreign service providers have established in the south of the country in response to better opportunities for research, technology, and equipment related to the

FIGURE 2.15: Unemployment Rates in the Capitals of the Xth Region (Puerto Montt) and XIth Region (Puerto Aysén) (Instituto Nacional d'Estadísticas 2011)

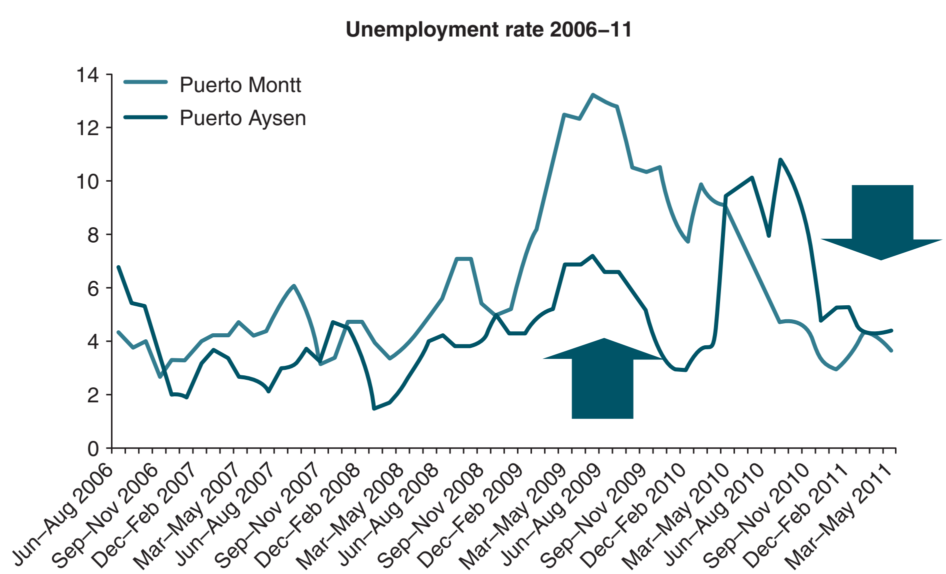
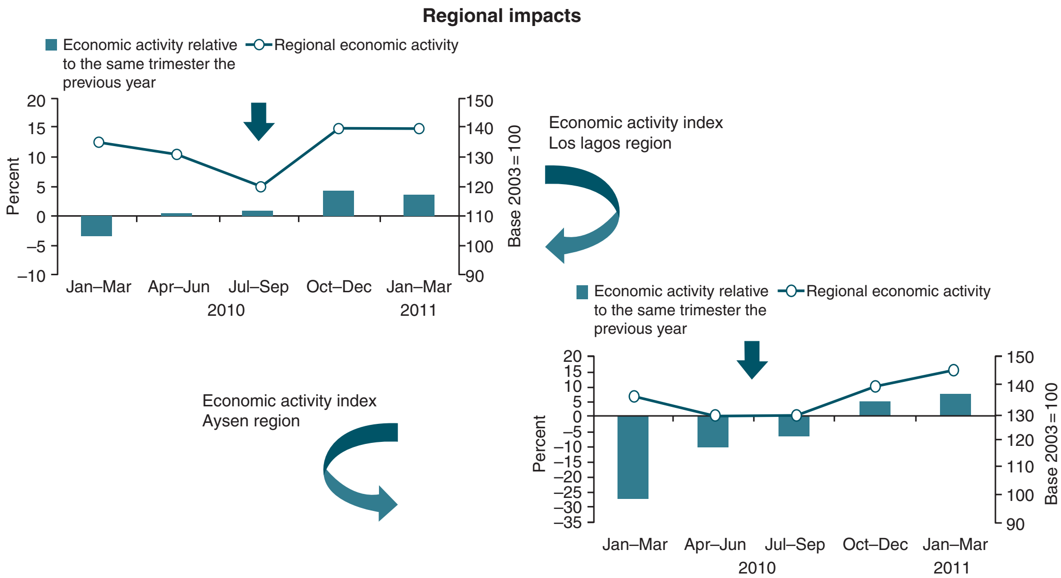


FIGURE 2.16: Economic Activity Index Reflecting the ISA Impact on Regions X and XI in 2010 (Instituto Nacional d'Estadísticas 2011)



implementation of the new biosecurity rules. Additionally, several of the professionals laidoff from the producer companies due to the crisis have created their own companies selling environmental/sanitary compliance systems focusing not just on the salmon industry, but also on other aquaculture ventures in Chile and other countries, particularly Brazil, Peru, Ecuador, and Central America.

2.5 SUSTAINABILITY OF THE NEW CHILEAN SALMON INDUSTRY

Key Elements for a Better Future

The Chilean salmon farming industry has recovered quickly and well from the ISA crisis and there are reasons to have an optimistic view about its future. They include:

1. The importance of salmon farming to the Chilean economy, which means that government is especially responsive to its needs in a way that was not always the case when the industry was smaller, or is the case in other countries where the industry is not such an important economic sector.
2. The intense efforts of SUBPESCA and SERNAPESCA during and since the crisis are evidence of this renewed interest, as also is the Ministry of Economy's plan to establish a new Undersecretariat of Aquaculture later in 2011, or early in 2012, with the goal of growing the industry to US$5 billion in sales by 2020.
3. Salmon farms are mostly corporately owned and professionally managed. Though overly aggressive farm expansion from 2000 to 2007 likely contributed to the ISA crisis, the industry's response, once the problem was recognized, was disciplined and professional. Members of SalmonChile, especially, showed themselves willing to learn from mistakes and to take the tough actions needed to bring things back under control.
4. The Chilean banks and financial community understand and believe in Chile's strengths as a salmon farming country, as illustrated by their supportive role during the crisis and the success of some public share offerings since.

Challenges on the Horizon

The question now is: will this impressive response from all the key players in the midst of a crisis be sustained to ensure the industry's long-term growth and viability? Some outstanding issues are going to be hard to resolve. For example:

1. The use of lakes and estuaries for producing smolts, especially of Coho salmon and trout. Can this be done in a way that maintains adequate biosecurity?
2. Definition and redrawing of production zones so that they are hydrographically accurate.
3. Definition of zone carrying capacity and clear guidance on how space should be allocated among concession owners.
4. Reconciliation of the requirements for synchronized production and fallowing in zones that do not fit well with

the production cycle of one or more of the three different culture species, or that make it difficult for smaller companies to maintain continuous production.

5. Simplification of the ownership of concessions within zones to make it easier to manage them on a single-year class production cycle.
6. Creation of new approved aquaculture areas to allow industry expansion while also accommodating the needs of existing users of the space.

These are all matters the resolution of which, ultimately, requires government policy, decision making and enforcement, though government recognizes that satisfactory outcomes are only likely if the industry, researchers, and other private sector participants work together. These types of collaborations have been highly successful in the response to the ISA crisis, and mechanisms are now in place to allow such dialogue to continue. For example, in March 2011, SUBPESCA appointed the Panel of Experts to:

Prepare the Health Regulations for Aquaculture.

- Analyze the potential for creating 'macrozones'.
- Review methods for the smoltification of salmon and trout.
- Complement the technical and health vision of the Ministry of Economy, while looking at the economic and social effects of the measures proposed.

This panel's work has already resulted in the publication of proposed modifications to the sanitary regulations in August 2011 and recommendations on smoltification at the end of September 2011.

In addition, the Salmon Board, which was originally established to bring government and the private sector together to formulate the changes in the 2011 Fisheries and Aquaculture Law, has been reconstituted and now includes a subcommittee that will develop recommendations on:

- *Industry governance*—including information management, enforcement, transparency, timely communication, and coordination within government, especially relating to diagnostic and surveillance work.
- *Production mode*—setting goals and controls for future production, trying to answer the question: how much salmon can Chile produce without risking another crisis?
- *Zoning*—dealing with all the issues relating to accurate definition and use of production zones, including relocation of concessions where necessary and the setting of limits on production.
- *Research and development*—identify research priorities, how work on them should be funded, and how this should be coordinated between industry, universities, and research centers. Examples include improving the efficacy of vaccines and compliance with food safety and other standards in foreign markets.
- *Infrastructure*—recommend improvements to facilitate farming in remote areas and to reduce biosecurity risks from infrastructure that is shared between zones.

The effective public-private dialogue that was established in the heat of the crisis is thus set to continue and suggests that the more difficult longer term issues will be resolved. If there is reason for concern, it is the challenge that government and its private sector collaborators will face in crafting and implementing new policy quickly enough to keep pace with the industry's renewed enthusiasm.

Understandably, Chilean salmon farming companies want to take advantage of the much improved performance they are now seeing in their fish and to recapture markets lost in the depths of the crisis. They are eager to increase production once more. But investment decisions to stock more smolts or to restock idle farms can be made more quickly than new policies can be developed and implemented. As the public-private dialogue continues it must seek to find a balance that will ensure that growth is sustainable.

Industry's Responsibilities

As noted above, it is generally believed that sustainable production of farmed salmon for Chile is around 700,000 tons, based on the present number of licenses and fallowing periods. Monitoring environmental, health, and production indicators will determine whether this is indeed the biological capacity of the system. To achieve environmental and economic sustainability and to reduce the risk of another disease crisis, the industry will need discipline to abide by the new regulations. To facilitate this, the industry must build a stronger relationship with its workers and the communities within which it operates, so there is a local sense of ownership of their product.

There are other challenges too. According to the former president of SalmonChile, César Barros, the challenges facing the new Chilean salmon industry in the near term (2011–15) include:

a. maintaining and preserving sustainable growth,
b. establishing a new and improved reputation for care and responsibility in environmental, employment and political matters, and
c. recovering the market lost due to the ISA crisis.

CHAPTER 3 CASE STUDY II: THE SHRIMP ACUTE HEPATOPANCREATIC NECROSIS SYNDROME OUTBREAK IN VIETNAM

GEORGE C. CHAMBERLAIN DONALD V. LIGHTNER LE VAN KHOA NGUYEN VAN HAO HOANG TUNG TRAN HUU LOC MELBA REANTASO

OUTLINE

3.1 BACKGROUND

Southeast Asia constitutes the largest and most productive shrimp farming region in the world. Beginning in about 2009, a new, emerging disease called "Early Mortality Syndrome or EMS" (more descriptively called acute hepatopancreatic necrosis syndrome or AHPNS) (Lightner 2012) began to cause significant production losses in southern China. By 2010 the range of affected farms in China had expanded, and by 2011 EMS was confirmed in Vietnam, Thailand, and Malaysia (Flegel 2012; Leaño and Mohan 2012). EMS has caused serious losses in the areas affected by the disease, and it has also caused secondary impacts on employment, social welfare, and international market presence.

History of Shrimp Farming in Vietnam

Shrimp farming in Vietnam began nearly 50 years ago when farmers found that in low-lying coastal areas, they could flood levied areas at high tide and trap postlarval and juvenile stages of penaeid shrimp, different crabs and several fish species. Such extensive systems required no feeding, and the shrimp, crabs, and fish could be harvested and marketed locally.

About 30 years ago, the first shrimp hatcheries were opened. These produced postlarvae (PL) from wild caught broodstock, which in Vietnam was mostly the Black Tiger Shrimp, *Penaeus monodon*. This step led to the development of semi-intensive culture systems in the country. In the past decade, further advances in culture systems were developed and many shrimp farming companies incorporated intensive culture systems into their farming schemes.

The introduction of specific pathogen-free (SPF) lines of the Pacific White Shrimp, *Penaeus vannamei* began in the past 4–5 years, and this species is primarily used in intensive culture systems.

The Vietnamese Shrimp Farming Industry

The European Union SEAT Project (http://seatglobal.eu/) estimated that in 2012 about 660,000 ha of ponds are being used for shrimp farming in Vietnam, 90 percent of this in the Mekong Delta (figure

FIGURE 3.1: Principal Shrimp Growing Areas in the Mekong Delta of Vietnam

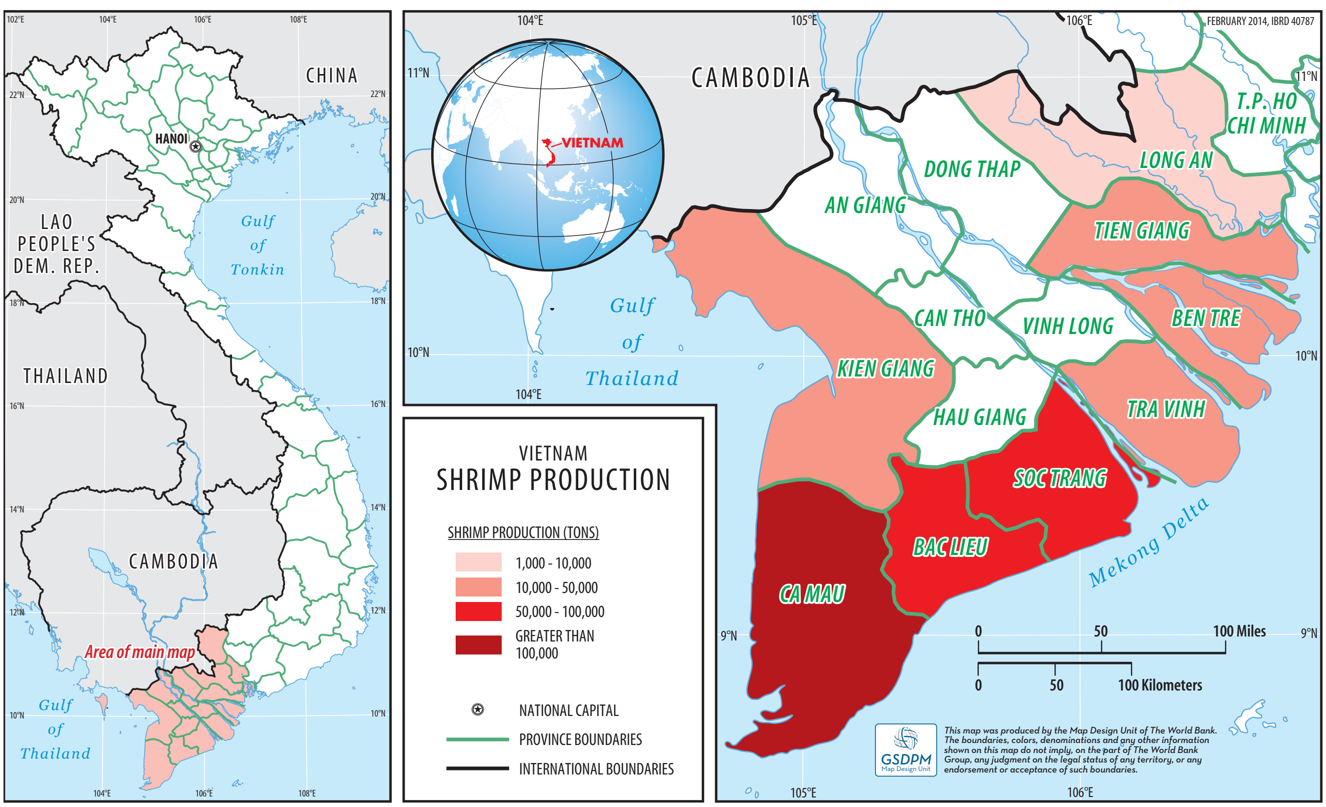


FIGURE 3.2: Extensive (left) and Semi-intensive (right) Shrimp Farming in Southern Vietnam. Extensive Farms Rely on Water Exchange with the Irrigation System to Maintain Water Quality, but Permitting the Entry and Exit of Diseases. The Use of Aeration Permits Intensive Farmers to Increase Stocking Densities While Isolating the Ponds from the Adjacent Canals (Photos: RE Brummett)

3.1). Three general types of shrimp farms are listed for Vietnam. Extensive farms typically use simple technologies, have relatively low production rates per crop, and may use little or no supplemental feeding during production (figure 3.2). Stocking rate on extensive farms is between 3–6 PL/m^2, and harvests vary from 250–700 kg/ha. Approximately 90 percent of the shrimp farming area in the Mekong Delta is of extensive ponds, which accounts for some 62 percent of total production.

Semi-intensive farms require more management than do extensive farms, with daily feeding and water management for maintaining dissolved oxygen and phytoplankton blooms at optimum levels. Typically, semi-intensive ponds do not have supplemental aeration, stock at 10–15 PL/m^2, and harvest 1.0–2.0 tons/ha. This system accounts for 2 percent of culture area and is responsible for 4 percent of production.

The third type of shrimp farm management is done with the use of intensive shrimp culture technology. Such ponds are generally smaller than extensive or semi-intensive ponds, are fed multiple times per day, average about 0.5 ha in surface area, and have from 2 to 6 or more horsepower of mechanical aeration per pond. Intensive systems stock 20–40 PL/m^2 and harvest 2.5–6 tons/ha. This system occupies 8 percent of the total culture area but accounts for 34 percent of total production. Most intensive production is in Soc Trang and Bac Lieu provinces.

Shrimp farms in Vietnam generally consist of multiple ponds located adjacent to a water source which in the Mekong Delta area is usually a canal (figure 3.3).

A key feature of the Mekong Delta where most of the Vietnamese shrimp industry is based is the dense system of irrigation canals that fill and drain the ponds. Initiated by the French colonial administration for transportation, these have evolved into a massive network that effectively connects all the farms to a single common water resource. This connectedness, whereby the water source

FIGURE 3.3: Vietnamese Ponds Often Use the Same Canals for Intake and Discharge of Water. This Facilitates the Transmission of Disease among Farms (Photo: D Duggar)

and discharge are from and into the same canals that serve all the other farmers, facilitates the spread of disease, especially in areas with a high density of extensive and semi-intensive shrimp farms such as Ca Mau. These farms are more dependent upon flowing canal water through their ponds to maintain oxygen levels than intensive, aerated farms.

Industry Associations

A variety of unions, associations, and clubs support the development of the fisheries/aquaculture sector. These include the Labour Union of Vietnam's Fisheries Sector, Vietnam's Fisheries Association, and the Vietnam Association of Seafood Exporters and Producers (VASEP). VASEP is a nongovernmental organization, based on the principles of volunteerism, autonomy, and equality. VASEP members include leading Vietnamese seafood producers and exporters and companies providing service to the seafood sector. The association was established in 1998 to coordinate and link enterprises and operations, based on mutual supports to improve value, quality, and competitive capacity of Vietnamese seafood, enhance creating raw material for seafood export, and represent and protect legal interests of members.

The My Thanh Shrimp Farmers Association (MTSFA) is an example of a regional industry association in Vietnam. MTSFA is responsible for collecting, updating, and providing information on shrimp crop, harvesting time, quality, output, and shrimp counts in Soc Trang province and neighboring provinces, introducing modern technologies in shrimp farming, informing members of food safety and hygiene standards as well as management regulations, providing market information, and maintaining a list of compliant and noncompliant shrimp farming households. MTSFA also collaborates with VASEP to promote the safety and quality of Vietnam shrimp. In a meeting that the expert team had with the MTSFA on July 31, 2013 there were approximately 20 shrimp farmers present.

At the local level, shrimp farming clubs have been established in various provinces to help improve linkage and cooperation among farmers. The first shrimp farming club began in 2008, when the Agriculture and Fishery Extension Center (under Tra Vinh Department of Agriculture and Rural Development) developed a pilot model in Cai Ga hamlet, Hiep My Dong commune, Cau Ngang district. Initially, the club included 10 members with the shrimp farming area of almost 10 ha. Members of the club were given technical support in pond cleaning, frying selection, managing of shrimp health, and disease prevention for shrimp, which led to greater profitability.

By the end of 2008, Tra Vinh developed seven clubs with 7–10 members per club. Continuing success inspired the Agriculture and Fishery Extension Center in Tra Vinh province to set up 10 shrimp farming clubs with the participation of 90 members, mainly in two districts (Hiep My Dong and Hiep My Nam) and sent experts to the localities to transfer technology in shrimp breeding. Experts gave members of the clubs instructions and guides on timing of shrimp stocking, seed selection, water management, pond management, and wastewater treatment. Members of clubs typically generate 20–25 percent higher profits than nonmembers through assistance from experts, sharing of information among members, and cost sharing on such expenses as disease testing of shrimp seed.

Despite these mostly local efforts to organize the shrimp farming subsector, the vast number of shrimp farmers in the Mekong Delata, an estimated 243,000 (F Murray, Stirling University, personal communication), makes any kind of collective action extremely difficult. Compounded by confusion over the cause of the EMS, the producers' associations were more or less helpless in guiding their membership to avoid the disease.

Vietnamese Government Structures

Vietnam's governing law for fisheries has been adjusted in recent years and was reissued in 2004 by the president (FAO 2005). The fisheries law consists of 10 chapters and 62 articles; these chapters incorporate: general regulations; protection and development of aquatic resources; capture fisheries; aquaculture regulations; regulations for fishing boat and fisheries services; regulations on processing, trading, export, and import of aquatic products; regulations on international cooperation for fisheries operations; regulations on governmental administration of fisheries; and regulations on rewards and sanctions as well as regulations on clauses for implementation. There are also a number of decrees, decisions, and so

forth issued at government and ministerial levels on specific tasks to support the management of the fisheries sector.

The Ministry of Agriculture and Rural Development (MARD) is the governmental agency responsible for management of agriculture, forestry, salt production, fishery, irrigation/water services, and rural development nationwide. Among the Ministries and Departments within MARD are the Directorate of Fisheries (DOF) and the Department of Animal Health (DAH). There are three administrative levels within the fisheries sector including the central (national), provincial, and district levels. The institutional organization of the fisheries sector includes divisions and specialized institutions and associations. Specialized institutions support DOF with regard to research and development. These are the Research Institute for Marine Fisheries, the Institute for Fisheries Economics and Planning, the Research Institute for Aquaculture No. 1 (based in Bac Lieu near Hanoi); the Research Institute for Aquaculture No. 2 (based in Ho Chi Minh City [HCMC]), the Research Institute for Aquaculture No. 3 (located in Nha Trang City in Khanh Hoa province in south-central Vietnam) and the National Fisheries Extension and Information Center.

DAH is comprised of seven regional animal health offices and 63 provincial laboratories. The main laboratory, the National Center for Veterinary Diagnostics, is located in Hanoi. DAH6 in particular is located in HCMC and is a modern, well-equipped and well-staffed laboratory. As a first step in planning to further upgrade these services, a World Organization for Animal Health (OIE) Review of the Performance of Veterinary Services has been conducted, but the results have not yet been made public.

Principal Shrimp Health Issues Prior to EMS/AHPNS

Prior to the emergence of EMS/AHPNS in Vietnam in 2009 or 2010, the country's shrimp farming industry was adversely affected by several significant diseases of *P. monodon* and later of *P. vannamei*. The most important of these are infectious hypodermal and haematopoetic necrosis (IHHN) virus, taura syndrome virus (TSV), vibriosis, monodon-type baculovirus or spherical baculovirosis (OIE 2009a) and white spot disease (WSD) caused by white spot syndrome virus (WSSV), an OIE-listed pathogen (OIE 2012).

Infectious myonecrosis disease (caused by IMNV) has been suspected in Vietnamese shrimp farms for the past 3 to 4 years, according to test results from commercially available kits. However, to date the presence of IMN in Vietnam has not been confirmed by a qualified laboratory outside of Vietnam (Flegel 2012; Senapin et al. 2011). Hence while IMN remains suspect in Vietnam, its presence remains unconfirmed using the OIE-approved methods of reverse transcriptase polymerase chain reaction (RT-PCR) and/or histopathology as given in the OIE Diagnostic Manual for Aquatic Animal Diseases (OIE 2009b).

A few minor diseases have also been found in cultured populations of shrimp in Vietnam, but these are not widespread, nor have they had major adverse effects on the Vietnamese shrimp farming sector.

3.2 DESCRIPTION OF EMS/AHPNS

Heavy mortalities during the early stages of a shrimp crop are not unusual and there is a variety of management- and pathogen-related factors that can cause such losses, which are often described by the catchall term "early mortality syndrome."

However, in 2009 a new and distinctive pattern of mortalities began to be noticed, affecting both *P. vannamei* and *P. monodon*. The syndrome involves mass mortalities of up to 100 percent during the first 20–30 days after stocking. Affected shrimp consistently show an abnormal hepatopancreas, which may be shrunken, swollen, or discolored; loose shells; corkscrew swimming; pale coloration; and slow growth.

An Emergency Regional Consultation on EMS/AHPNS of Shrimp organized by the Network of Aquaculture Centres in Asia and the Pacific (NACA) and the Department of Agriculture Fisheries and Forestry of Australia (DAFF) in August 2012 recommended the following case definition:

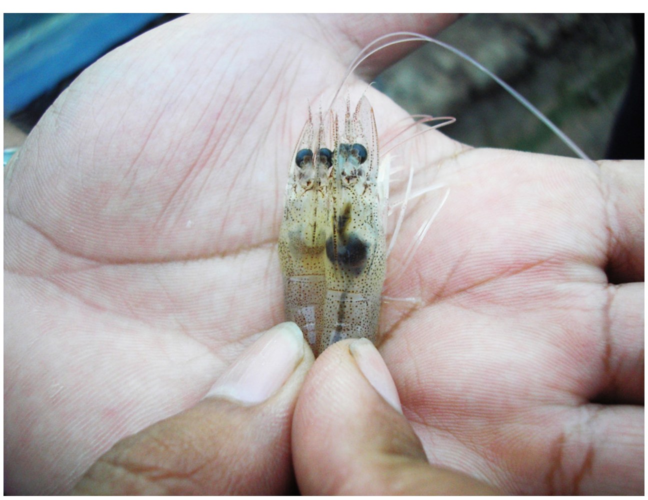
Acute progressive degeneration of the hepatopancreas from medial to distal with dysfunction of B, F, R and E cells, prominent karyomegaly and necrosis and sloughing of these tubule epithelial cells. The terminal stage shows marked inter- and intratubular hemocytic inflammation and development of secondary bacterial infections that occur in association with necrotic and sloughed hepatopancreas (HP) tubule cells. Sometimes common in the terminal phase are melanized HP tubules with the lumens of the affected tubules containing masses of sloughed HP epithelial cells and masses of bacteria.

At the pond level, the following clinical signs can be used for presumptive diagnosis which can be further confirmed by histopathology at the animal level by using the above case definition:

- Often pale to white within HP connective tissue capsule.
- Significant atrophy of HP.
- Often soft shells and partially full to empty guts.
- Black spots or streaks within the HP sometimes visible.
- HP does not squash easily between thumb and finger.
- Onset of clinical signs and mortality starting as early as 10 days' post stocking
- Moribund shrimp sink to bottom.

The gross signs of AHPNS (figure 3.4) are evident by simple pond-side examination of affected shrimp accompanied by a simple dissection and examination of the hepatopancreas. These signs may become apparent as early as 10 days post stocking of a recently prepared pond. Shrimp with AHPNS will show a pale to white HP due to pigment loss in the HP connective tissue capsule and a loss of pigment storage in the R-cells of the HP; atrophy of the HP that may reduce the expected size of the organ by 50 percent or more; black streaks or spots in the HP (that represent melanized HP tubules [see next section]; the HP may not squash as easily as a normal HP when rubbed between the thumb and forefinger; affected shrimp may show soft shells and empty guts; and such affected shrimp do not float and typically may be found on the pond bottom.

FIGURE 3.4: Healthy (left) and EMS-Infected (right) Shrimp. In Healthy Shrimp Note the Full Stomach, Full Mid-Gut, and Large, Dark Hepatopancreas. In the EMS Shrimp, Not Empty Gut and Stomach, and Shriveled, Pale Hepatopancreas. (Photo: DV Lightner)



EMS that caused by a bacterial agent that is transmitted orally, colonizes the shrimp gastrointestinal tract and produces a toxin that causes tissue destruction and dysfunction of the shrimp digestive organ known as the hepatopancreas. Through a concerted international effort, the EMS/AHPNS pathogen has been tentatively identified as a unique strain of a relatively common bacterium, *Vibrio parahaemolyticus*, which seems to be infected with a phage, a virus-like particle that inserts itself into and modifies normally harmless vibrio DNA to produce highly toxic gene products that kill young shrimp. It seems to be harmless to humans.

3.3 THE EMS/AHPNS CRISIS

EMS/AHPNS adversely affects shrimp during the first 30 days post stocking. Hence, the disease has also been called "30 day mortality syndrome." At affected farms, the disease may become apparent in as little as 7 to 10 days' poststocking or as much as 1 to 3 months later. However, the most typical presentation of EMS/AHPNS is between 7 to 10 days' poststocking to as long as 45 to 60 days' post stocking. The disease is spread when infected farms harvest the shrimps and discharge wastewater into the surrounding environment.

First Reports of EMS/AHPNS in Vietnam

The first reports of EMS/AHPNS were released in April 2011 in response to losses in Soc Trang and Bac Lieu provinces in the Mekong Delta region of Vietnam. An epidemiological survey of the entire country found that the disease had been present at least 1 year earlier in May of 2010 in Soc Trang province. Confirming this observation was a diagnostic case submitted to the University of Arizona Aquaculture Pathology Laboratory (UAZ-APL). In 2010, UAZ-APL received samples with the disease from the Lieu Tu commune, Tran De district of Soc Trang province. Shrimp producers in this area of Soc Trang province reported that, according to gross signs presented by affected shrimp, the disease was present in 2009.

By 2012, the disease was widespread in Vietnam, especially in the Mekong Delta, and was reported in shrimp farming areas of south-central and northern Vietnam. According to the My Tranh Shrimp

Farmers Association (MTSFA), 70 to 90 percent of farms were affected and losses were estimated at 20–80 percent of the crop (50 percent on average).

Reported losses due to EMS/AHPNS in 2010 were estimated by NACA and DAH to be 87,113 tons valued at US$484 million; in 2011 the losses were estimated at 285,000 tons and valued at US$1.6 billion; by mid-2012 losses were estimated at 201,000 tons and valued at US$1.05 billion. Five provinces were affected by EMS/AHPNS in 2010 and included: Soc Trang, Bac Lieu, Ben Tre, Bac Lieu, and Ca Mau provinces; in 2011, 10 provinces were affected including: TT Hue, Quang Nam, Binh Dinh, Ninh Thuan, Soc Trang, Tien Giang, Kien Giang, Tra Vinh, Bac Lieu, and Ca Mau provinces, of which four reported to FAO (2013) lost production (in terms of hectarage) of:

- Tra Vinh Province (6,200 ha in 2011)
- Soc Trang Province (20,000 ha in 2011)
- Ca Mau Province (15,000 ha in 2010–11)
- Bac Lieu Province (11,000 ha in 2011).

By mid-2012 the disease had spread into 19 provinces including: Ninh Binh, Thanh Hoa, Nghe An, Ha Tinh, Quang Binh, Quang Tri, TT Hue, Quang Ngai, Binh Dinh, Phu Yen, Ninh Thuan, Binh Thuan, Tien Giang, HCMc, Ben Tre, Tra Vinh, Soc Trang, Bac Lieu, and Ca Mau provinces. Personnel at Research Institute for Aquaculture No. 3 (RIA3) reported that Khanh Hoa province in southcentral Vietnam was also affected by EMS/AHPNS. The widespread nature of EMS/AHPNS in Vietnam, 52,000 ha, is consistent with the confirmed presence of EMS/AHPNS in adjacent regions of China, Malaysia, and southeastern Thailand (NACA 2012).

Impact of EMS/AHPNS on Vietnamese Shrimp Farms

While no official data are available on the economic impact of EMS/AHPNS on the Vietnamese shrimp farming industry, Vietnam's reduction in production can be estimated from information provided by members of the expert team. According to information from members of this team, little significant impact was noted for overall Vietnamese production in 2009 and 2010. In 2010, Vietnamese shrimp production was estimated to be about 480,000 metric tons. However, by 2011 the disease had become widespread in the Mekong Delta resulting in a decline in overall production to an estimated 320,000 metric tons, and for 2012, the country's production was expected to be about 300,000 metric tons (GAA unpublished). Assuming an average farm-gate value of US$5/kg, income/production losses were approximately US$800–900 million in each of 2011 and 2012, not including impacts at the processing and export level. Officials at the World Bank Office in Hanoi estimated that 31,000 to 32,000 ha were affected by EMS/AHPNS in 2011. The number of affected hectares grew to 38,000 ha by mid-2012.

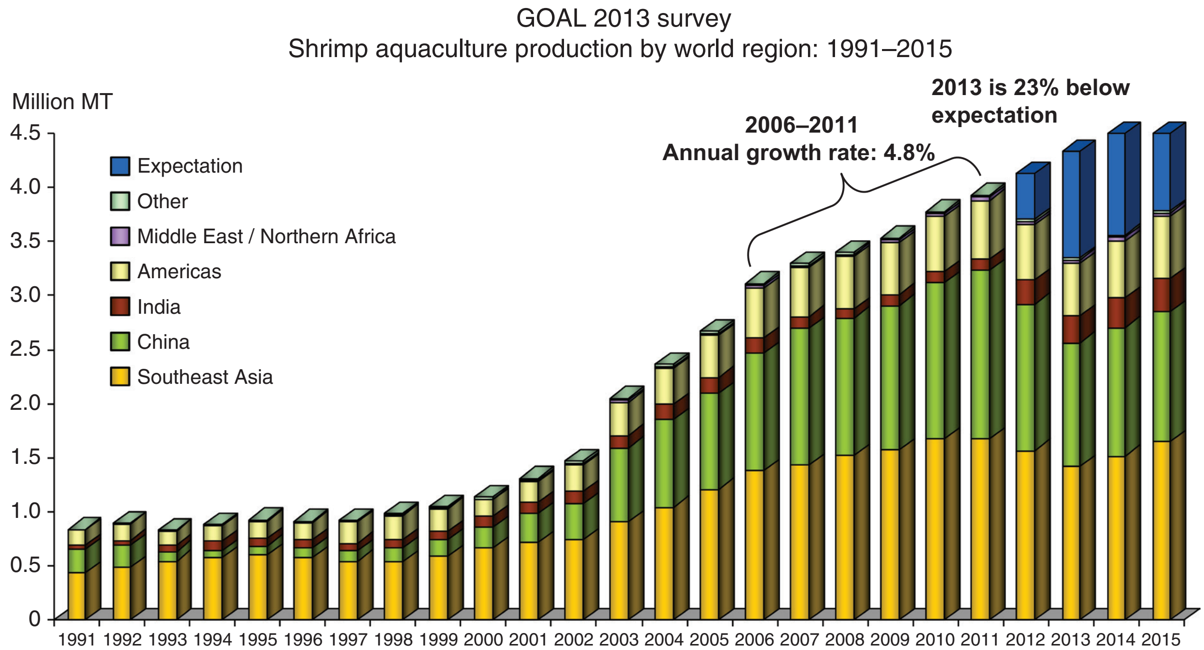
Major losses were noted in the first stocking/crop (from February to May) with more than 50 percent of the farms in the Mekong Delta region affected. In the second stocking/crop (June to October), the situation was somewhat improved with some farmers producing some harvestable production. The large farms in the western part of South Vietnam were largely unaffected by the disease in 2011. In 2012, the situation had not improved, and by the end of June, about US$100 million in lost production was estimated. In Tra Vinh in 2012 losses were also significant, particularly for *P. monodon*. Infected areas were restocked but EMS continued to thrive. At the moment it is estimated about 20 percent (11,000 ha) of the culture area was infected. Higher mortality has been observed in areas with high salinity or using intensive models. Economic loss is circa US$95 million, making life difficult for local people and having a significant impact on the global shrimp supply (figure 3.5).

Typical percentages of mortality in ponds with the disease are reported to range from 40 to 100 percent, regardless of the pond type and management style. Another estimate for August 2012 for some affected farms in Ba Ria Vung Tau typical mortalities due to EMS/AHPNS were 70–80 percent. Lined ponds and unlined ponds were equally affected in the affected farming areas, and both semi-intensive and intensive farms were equally affected.

Impact of EMS/AHPNS on the Shrimp Value Chain

Not only shrimp farmers have been adversely affected by EMS/AHPNS, resulting in significant job losses in many shrimp farms in the affected provinces, but the disease has also resulted in some lost jobs in companies that process, pack, and export shrimp. Likewise, feed sales to regions of Vietnam affected by the disease have declined significantly. To minimize the negative effects of EMS/AHPNS, some large companies in Vietnam have been importing shrimp from adjacent countries in an effort to minimize the negative effects of the

FIGURE 3.5: Impact of EMS on Global Shrimp Aquaculture Output. China and SE Asia Are the Hardest Hit, but Recent Reports of an Outbreak in Mexico Could Adjust Downward Production from the Americas (GAA unpublished)



Sources: FAO 2013 for 1991–2011; GOAL 2013 for 2012–2015. Southeast Asia includes Thailand, Vietnam, Indonesia, Bangladesh, Malaysia, Philippines, Myanmar, and Taiwan. *M. rosenbergii* is not included.

disease on their processing and exports. Small processing and shrimp packing companies have not done as well as the larger companies that can afford to import shrimp from neighboring countries for processing and export. While this activity is helping the processing and export industry of Vietnam for the short term, this is not likely to be a sustainable practice, especially as more neighboring countries experience the disease in their shrimp farming sectors.

Perhaps intuitively, the sale of chemicals needed to prepare ponds for stocking has been less affected by the disease as many farmers will often attempt repeated restockings of PLs into chemically retreated ponds. This activity has also had some positive effects on the shrimp hatcheries in Vietnam as they probably produced and sold more PLs in 2011 and early 2012. However, because the shrimp farmers in affected regions of Vietnam are refraining from restocking their ponds (after destroying affected ponds), the increased sale of PLs is not likely to be sustainable. The reluctance of many shrimp farm owners to delay restocking or leave affected farms fallow has resulted in significant losses of employment at shrimp farms.

At the farm level, and to some extent the feed and processing plant level, many previously employed workers have become unemployed and were forced to leave their hometowns, near the farms that once employed them, to find jobs elsewhere. Hence, the impacts of EMS/AHPNS crisis have been both economic and social.

3.4 DISCOVERING THE CAUSE

Before anything truly useful could be done, the cause of the disease had to be identified. Most of the Vietnamese institutions in aquaculture research were involved, including: Nong Lam University, University of Minh Thuong, the Institute for Agriculture Environment, MARD, RIA2, and RIA 3.

The presentation of the disease made diagnosis difficult. Seemingly contradictory evidence abounded during these early days. For example, the use of sedimentation ponds or water treatment in reservoirs did not alleviate the problem. Some environmental parameters (H_2S > 0.03 mg/L; NO_2- > 20.0 mg/L; SO_4) were high in affected ponds, but when animals were removed to a cleaner environment, some recovered and some died. On some farms, EMS occurred even when the water was treated with oxytetracycline (OTC), while other farms reported that the use of oxytetracycline stopped shrimp deaths "if water color is

good." Most problems were reported during March–July, a period characterized by rain and temperature fluctuations.

Because shrimp farms in Vietnam are often located on the same canal as are many other farms, the rapid spread of infectious diseases like white spot disease is common. Hence, because of this characteristic of Vietnamese shrimp farms and because WSD has a wide range of crustacean vectors of WSSV, the use of certain pesticides has been common in the industry to control potential vectors of WSSV in the water used to fill ponds before stocking. Common pesticides in use by the industry include cypermethrin, certain organophosphates, and synthetic pryethroids (carbamates). Some farmers indicated that only chlorine was being used for this purpose. A typical use of pesticides or chlorine would be to fill a pond with water and then apply the pesticide or chlorine to the water in the pond to achieve a dose sufficient to kill all potential vectors of WSSV. The pesticide or chlorine then dissipates to permit stocking within 7 to 10 days.

The use of numerous pesticides by the Vietnamese shrimp farming industry led some laboratories in Vietnam working on the disease to conclude that the use of cypermethrin was the cause, or at least among the factors responsible, for EMS/AHPNS. However, independent studies run at the UAZ-APL using the pesticide over a range of lethal and sub-lethal doses in chronic 28-day static renewal bioassays with *P. vannamei* and *P. monodon* failed to induce lesions of the hepatopancreas typical of EMS/AHPNS. Likewise, additional studies with cypermethrin added to soil and tested with shrimp for 28 days also did not induce pathology of the HP consistent with AHPNS. According to the MTSFA, EMS also occurred in ponds that did not use pesticides. Nevertheless, a decision was made by the government to stop the use of cypermethrin.

Algal toxins have also been suspected as a potential agent of AHPNS. However, surveys (in 2012) of phytoplanktonic algae collected from ponds with the disease failed to show the presence of phytoplankton such as dinoflagellates or certain blue-green algae known to be toxin producers. MTSFA reported to have seen EMS in ponds that had no toxic algal blooms.

RIA2 and Can Tho University reviewed successful farms to share lessons and experience. They collected samples every 3 days to monitor the syndrome and tried to identify some linkage with the PL source (locally produced PLs survived better in the system).

EMS seemed to appear even in rice-shrimp models or in extensive ponds (very typical clinical symptoms). Interestingly, some infected ponds, after being restocked, performed quite well. In some other areas, ponds were prepared again with adequate treatment, but shrimp were still dying.

Observation of the movement of EMS/AHPNS from China to Vietnam, Malaysia, and southeastern Thailand suggested that the agent of the disease moved as a commodity between the affected locations in these countries. The transboundary movement of broodstock and/or PLs might have been a potential source of the disease agent. Its occurrence in *P. vannamei* can be explained with this scenario. More difficult to explain with this hypothesis was the occurrence of EMS/AHPNS in *P. monodon* PLs and small juveniles that are produced from wild broodstock. One explanation for the occurrence of the disease in PLs and juveniles produced from wild caught *P. monodon* broodstock is that the disease has become established in many provinces in the affected areas of Vietnam, and, hence, the agent is present in the environment.

While some shrimp recover from AHPNS, many do not. Total failure of the HP, especially during the terminal phase of the disease, is characterized by massive vibriosis of the HP, leading researchers to look for a bacterial agent that might be present in the pond-bottom detritus. Pond-to-pond spread might be explained by the use of PLs that are infected with the agent when purchased, or by the transmission of the agent due to its lack of sensitivity to pesticides used to prepare ponds for stocking. *Vibrio cholerae* is a common species of vibrio that when infected by a phage produces a potent toxin that causes lesions to the mammalian intestine that are similar to those observed in AHPNS. Laboratory studies conducted at the University of Arizona point toward the possibility that a phage *V. parahaemolyticus* is also involved in the pathology of AHPNS (Tran et al. 2013).

3.5 MEASURES TAKEN IN RESPONSE TO THE EMS/AHPNS CRISIS

Initial Response

In addition to the all-out research effort aimed at discovering the cause of the disease, the government and the shrimp industry undertook a number of measures to try and control the damage. In an initial response to the outbreak, the government formed a National Task Force, which meets the minister every second week

to review progress. MTSFA also organized farmer meetings every second week with the local officers.

The government of Vietnam requested technical assistance of the Food and Agriculture Organization in July 2011. In response, FAO fielded a rapid deployment team through the Animal Health Crisis Management Center, which made a quick assessment. Based on epidemiological observations and other relevant field data, the CMC-AH confirmed that an outbreak occurred (since early 2010, continuing in 2011) with high mortalities among *P. monodon* and *P. vannamei*. The pattern of disease spread was consistent with an infectious agent, that is, starting in one pond in one location and subsequently spreading to several ponds within the farm, followed by spread to neighboring farms. The agent was not known in as much as the spread pattern and symptoms were not similar to those of any known major shrimp viral or bacterial disease. An FAO Technical Cooperation Program (TCP/VIE/3304) financed an international workshop in June 2013 to identify specific and generic actions and measures for reducing the risk of AHPND directed to wider shrimp aquaculture stakeholders (public and private sectors).

DAH and local authorities recommended a comprehensive protocol for disease prevention (seed quality, water quality management, improvement of biosecurity, strengthen disease control) but there were difficulties in accessing farms and limited capacity of local officers in terms of aquatic disease and, by and large, farmers did not follow the technical guideline issued by local authorities, at least in part due to lack of financial resources.

Some larger companies applied chemicals to create an "algal color." Application of these remedies, however, did little to control the disease while increasing production cost, making shrimp farming unprofitable.

The provincial authority established a panel and instructed farmers not to stock and attempted to disallow PL suppliers to sell PLs. Some 80 tons of chlorine were distributed by MARD to sterilize infected ponds, which had some effect and there were fewer problems reported in the second crop.

Experimental and Therapeutic Use of Antibiotics

Many farmers indicated that they were testing a variety of antibacterial compounds in an effort to control or prevent losses due to EMS/AHPNS. While some farmers reported reductions in losses due to the disease, others reported that the antibiotics they used were ineffective. Among the antibiotics reported being used by farmers, willing to discuss their use, was primarily OTC, but some farmers reported experimenting with other antibiotics such as enrofloxacin.

In Vietnam, feed companies are prohibited from making medicated feeds, probably because of the numerous instances where importing countries have found antibiotic residues in imported shrimp. Hence, antibiotic use on farms is achieved by top-coating normal feed prior to use with a preparation of water and the intended antibiotic. The aqueous mix is stirred into the feed and the feed is then fed to the pond to be treated for several days. Two companies acknowledged that they had used OTC feed for 3 days, followed by several days with normal feed, and then retreating the feed with OTC and feeding the top-coated feed for an additional 3 days. For antibiotics like OTC that are extremely water soluble, this practice is very unlikely to provide a significant dose of antibiotic to affected shrimp to be efficacious, especially those shrimp in the early or terminal phases of AHPNS which are likely off feed. It is very likely that the OTC mixed with feed in an aqueous suspension leaches from the top-coated feed within minutes of being fed to an affected pond.

Use of Probiotics

Probiotics are in common use in Vietnam. Some farmers in EMS/AHPNS affected areas reported to the World Bank/Responsible Aquaculture Foundation (WB/RAF) expert team that they were successfully using probiotics to manage losses due to the disease. At one large farm where the use of probiotics was reported as successful, the farm produced their own probiotics.

Many of the probiotic products sold in Vietnam have *Bacillus sp.* as the primary ingredient. Others have *Lactobacillus sp.* and *Vibrio spp.* like *Vibrio alginolyticus* as ingredients. While some farmers reported the successful use of probiotics, often neighboring farms reported no success in their use.

In general, controlled use of probiotics that would have enabled an assessment of their effectiveness was hampered by the presence of too many products on the market and variable quality (many are from overseas).

Change in Farming Methods and Strategies

Biofloc is an innovative, highly intense and closed system for fish and shellfish production (Avnimelech 2009). Biofloc systems have been reported as being tried in EMS/AHPNS-affected regions in Vietnam. The farmers indicated that the use of these systems may have resulted in some improvement in production, others who attempted to use such systems found EMS/AHPNS to occur equally in biofloc ponds and normally run intensive ponds. Hence, there was no clear improvement in culture performance in biofloc ponds over normal intensive ponds.

Some shrimp farmers commented that polyculture with species such as sea bass helped reduce losses due to EMS/AHPNS, presumably when fingerlings and PLs are stocked at the same time. Another strategy was to use only seawater from a pond with sea bass as the source water for a shrimp pond. The two versions of this strategy may have the same end result, namely the removal of vectors of WSSV from the source water, and as EMS/AHPNS develops, the removal of moribund or dead shrimp. If predation of shrimp by sea bass can be prevented by the two-pond strategy, the use of sea bass, or other marine or estuarine finfish, may help improve survival in shrimp ponds while helping to reduce risks associated with the introduction of WSSV with its normal vectors

3.6 RECOVERY AND PLANNING FOR IMPROVED BIOSECURITY

More rapid diagnostic methods need to be developed, and effective management methods employed to target the pathogen in its shrimp host or in the pond environment. Such methods might include the prudent and correct use of antibiotics, the use of probiotics that are intended to compete with the agent of EMS/AHPNS, the consistent use of biofloc systems, and the use of polyculture using one or more finfish species that can reduce the industry's dependence on the use of pesticides and chemical disinfectants in culture pond preparation. A long-term solution is to breed lines of disease resistance shrimp.

Shortcomings in the current industry constrain its ability to build disease resistant production systems. Among possible other issues, the study team note that:

- Smaller-scale, extensive shrimp farming cannot meet international standards of sustainable aquaculture as long as they are mixing influents with effluents.
- A complete program for environmental monitoring and disease warning is lacking.
- Overuse of chemicals/drugs is common among farmers (sometimes following the instructions of the suppliers).
- Farmers want to buy cheap PLs and often ignore disease risk. In most provinces, there is a lack of necessary facilities for disease diagnostics in hatcheries.
- Farmers tend to be conservative and independent, not readily taking on advice from outside experts.

Measures to Remedy the Situation

Suggestions for how Vietnam might address these shortcomings were identified through the close collaboration between the various research teams and fish farming groups and stakeholders who took part in this study:

- Reallocation of poorly-performing farmers to a well-designed zone with ample infrastructure.
- Research should be compatible to the local conditions of each province. Good models for intensive, semi-intensive, extensive farming need to be demonstrated.
- Need for education/training, particularly on disease diagnostics and management
- Need to develop demo-farms so that farmers can come to learn and share experience.
- Need to develop *L. vannamei* and *P. monodon* that are genetically resistant to EMS/AHPNS.
- Advise farmers how to treat intake water (for example, do not use cypermethrine, increase pH to 9.5)
- Carefully check the quality of PLs (that is, must come along with disease-free certificate). Farmers often look for cheap PLs so that stocking density can be higher.
- Enhance biosecurity at farm level.
- Farms should have a sedimentation pond for water treatment.
- Viet Good Aquaculture Practices (GAP) should be applied.
- Form and maintain farmers' association to share experience and support each other.

Management

Advances continue in the control of EMS/AHPNS via progress in breeding, hatchery and pond management, and feed additives.

However, the solution to the disease will likely involve an array of management practices.

Studies are examining the use of natural compounds as feed additives to disrupt the quorum sensing of the bacteria. The use of probiotic products can modulate the pond environment and the gut microflora in shrimp toward a more favorable composition.

Polyculture studies with fish such as tilapia have reduced EMS mortality in shrimp. This is thought to be caused by the blooms of *Chlorella* algae in tilapia ponds, which may disrupt the quorum sensing ability of *V. parahaemolyticus*.

Most farm biosecurity and pond management measures are designed to exclude viruses, which replicate only within the host. EMS is caused by bacteria that can thrive in the environment and not a virus. Consequently, its management requires new approaches. Studies at the Charoen Pokphand Foods EMS Challenge Center and elsewhere are pointing to a number of potential approaches and treatments.

For example, the use of intensive, highly biosecure production systems allows better control of the culture environment. The stocking of larger, nursery-raised shrimp has been effective in reducing EMS incidence. Both raceways and in-pond cages have been used successfully as nurseries.

Black tiger shrimp seem less affected than the more widely raised white shrimp by the EMS *Vibrio*. Black tiger shrimp tolerance of EMS is reportedly best in deep ponds with clean bottoms. For both white and black tiger shrimp, breeding efforts are seeking animals that exhibit greater tolerance of EMS.

FAO TCP/VIE/3304 (FAO 2013) contains relevant recommendations pertinent to the management of the disease, including: AHPND diagnosis; AHPND notification/reporting; international trade of live shrimp, shrimp products (frozen, cooked), and live feed for shrimp; advice to countries affected and not affected by AHPND; measures for farm and hatchery facilities; advice to pharmaceutical and feed companies and shrimp producers; actions on knowledge and capacity development; AHPND outbreak investigation/emergency response; and specific AHPND-targeted research (epidemiology, diagnostics, pathogenicity and virulence, public health implications, mixed infections, nonantimicrobial control measures, environment, polyculture technologies).

3.7 SUMMARY AND CONCLUSIONS

The EMS/AHPNS crisis has had a very significant negative impact on the Vietnamese shrimp farming industry, as well as that of neighboring countries that also farm shrimp. Key findings of this review of the problem include:

- The disease was recognized in China in 2009, but significant research did not begin until 2012, when it had already spread to several countries and caused losses in excess of US$1 billion. A mechanism is needed to allocate research funds before disease issues reach the crisis stage.
- To assure efficient, coordinated research, funds should be allocated with assistance from an expert multidisciplinary advisory board to help guide research and assure that the most appropriate technologies are being applied.
- Given the chronology of the disease, it apparently entered Vietnam from China. The most likely vector is infected broodstock or postlarvae. The epidemiology of the disease would be more apparent if movement of animals into each country were more thoroughly regulated and tracked. Movement documents are health records that should be required for all imported animals.
- Major outbreaks of EMS/AHPNS have been related to environmental conditions such as salinity and pH of pond water. Research has shown that the pathogenic *Vibrio* does not grow in water with less than 3 ppt salinity, but growth increases from 4 to 11 ppt, above which growth is unaffected by salinity. Noriaki Akazawa, general manager of the integrated Agrobest shrimp farm in Malaysia, found that shrimp mortality is greatly accelerated at high pH, while McIntosh reported that the pathogen itself is unaffected by pH from 7 to 9. This implies an indirect effect of pH. For example, the high pH in Agrobest ponds was caused by dense blooms of blue-green algae which may have also stimulated growth of the pathogen.
- Additional research has identified a relationship between pond water temperature and EMS, with outbreaks reaching peak intensity in the warm season. Excessive use of pond fertilizers such as molasses and urea has been found to stimulate the growth of virulent *P. parahaemolyticus*. EMS is also heightened in the presence of bryozoans, which appear

as calcareous tubules on the pond bottom. Bryozoans filter particulates from the water and are thought to concentrate the pathogen. Exposure to the EMS pathogen tends to be reduced when shrimp are reared in cages suspended above pond bottoms, and when ponds use well water instead of surface water.

- Sensitive testing methods that rapidly identify EMS/AHPNS in broodstock, postlarvae and juvenile shrimp have been developed by Lightner and team at the University of Arizona. DNA amplification and metagenomic sequencing of *V. parahaemolyticus* strains that cause EMS led to the design of polymerase chain reaction (PCR) diagnostic primer kits. The technology is expected to be licensed for distribution and commercially available in the coming months. Positive broodstock or postlarvae found positive using the tests should be destroyed or treated with approved antibiotics.
- In Vietnam, as in many shrimp farming regions throughout the world, multiple shrimp farms often use common water bodies for both intake and discharge. This makes these farms highly vulnerable to disease. Improved systems are needed to assure proper separation and treatment of intake and discharge waters.
- No single management method has been shown to be completely effective in eliminating EMS/AHPNS. Some companies or associations within the shrimp farming industry of Vietnam reported to the expert team that they had developed methods for reducing losses to EMS/AHPNS without knowing its actual causative agent. Other groups employing different methods (or no methods at all other than killing affected ponds and restarting with new PLs), have not been successful. Microcosm tanks which simulate the pond environment are recommended as a tool to evaluate and screen a variety of management techniques in a standardized, replicated manner.
- While the prudent use of antibiotics and probiotics may provide efficacy in reducing losses due to the disease, there is a large amount of variability in how antibiotics are used and how probiotics are applied. In Vietnam feed manufacturing companies are not permitted to manufacture medicated feeds that contain drugs like OTC, florfenicol, enrofloxacin, and others. Hence, when farmers intend to use medicated feeds even as experiments to treat EMS/AHPNS, they use a mix of water and the intended antibiotic to top-coat the feed for a particular pond. OTC was the most common antibiotic mentioned by those farming companies that acknowledged its experimental and therapeutic use for controlling EMS/AHPNS. The farmers that discussed how OTC is used at their farms indicated the use of an aqueous top-coating method and they feed such feeds for only 3 days before returning to using normal, unmedicated feeds. The expert team was informed that if a single 3-day treatment with OTC-medicated feed was not efficacious in resolving an EMS/AHPNS outbreak, then additional treatments with 3-days on OTC and several days off would be carried out.
- The misuse of antibiotics like OTC may even be complicating the situation in Vietnam because of the manner in which the antibiotic is used can lead to rapid development of resistance in bacteria such as members of the family *Vibrionaceae*. This family includes several genera of significant pathogens of penaeid shrimp (for example, *V. parahaemolyticus* and *V. harveyi*), and because the family contains species that cause similar pathology (for example, sloughing to HP tubule epithelial cells) in the intestine of mammals, the family may contain the agent of EMS, assuming that the disease is found to be infectious. There may need to be a change in regulations governing the manufacture of medicated feeds by feed companies and their use by shrimp growers. The current use of top-coating of feed with aqueous suspensions of antibiotics like OTC is unlikely to work and may lead to further development of drug resistant strains of bacteria, such as shrimp pathogens like *V. parahaemolyticus* and *V. harveyi*.
- The use of probiotics is also highly variable among the farms visited in the Mekong Delta area of South Vietnam. While one major farm reported to the expert teams that a non-disclosed mixture of probiotics was being successfully used to prevent EMS/AHPNS, other farmers in the same district did not find probiotics to show any efficacy. These observations suggest that the types of probiotics in use in Vietnam (from commercial and noncommercial sources) are highly variable and that some types being used may have no efficacy, while others may be beneficial. Perhaps the mixture of several probiotics (which the expert team was told are being produced by the farm staff) has components that interfere or compete for nutrients with the agent of EMS/AHPNS.
- The expert team was also informed by several companies and organizations that the use of biofloc systems was efficacious in resolving EMS/AHPNS. The pond systems shown

to the expert teams were not biofloc systems, and at best could only be described as semi-biofloc systems. The results in such systems for controlling EMS/AHPNS were variable among farms, with some reporting improved survival and growth and others reporting no improvement between semi-biofloc ponds and normal intensive ponds. Hence, the successful application of semi-biofloc systems was too variable to be considered as a method that could be applied to resolve the EMS/AHPNS crisis.

CHAPTER 4 CASE STUDY III: SHRIMP WHITE SPOT SYNDROME VIRUS OUTBREAK IN MOZAMBIQUE AND MADAGASCAR

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OUTLINE

4.1 WHITE SPOT DISEASE

History of WSSV Outbreaks Worldwide

White spot disease (WSD) is a contagious viral disease of penaeid shrimp caused by the white spot syndrome virus (WSSV). From origins in Southeast Asia, the disease has spread throughout the world. The economic losses due to WSSV have been devastating, totaling at least 8 billion dollars since 1992.

The first known outbreak of WSD occurred in Taiwan in 1992, where farmed shrimp of three different species (*Panaeus monodon*, *Marsupenaeus japonicus*, and *Fenneropenaeus penicillatus*) all experienced outbreaks of WSD (Chou et al. 1995). The disease spread to Japan in 1993 where it was reported from farmed *M. japonicus* (Inouye et al. 1994; Nakano et al. 1994), and the People's Republic of China (Huang et al. 1995). A variety of different names were applied to the virus causing these outbreaks, but all were describing a disease with similar gross signs and caused by a similar rod-shaped virus (Lightner & Redman 2010). Over the next few years the disease became widespread throughout Southeast Asia, spreading to Vietnam, Thailand, Malaysia, Indonesia, and India, causing hundreds of million of dollars in economic losses for the shrimp industry every year. At this time *P. monodon* was the dominant species cultured in Southeast Asia, and most of the postlarvae (PLs) were produced from wild broodstock. As it became increasingly difficult to find disease-free broodstock, the Southeast Asia shrimp aquaculture industry began to switch to *Litopenaeus vannamei*, a species for which domesticated specific pathogen-free (SPF) broodstock were readily available. Stocking disease-free PLs improved survivals, and the economics of growing *L. vannamei* were more favorable since *L. vannamei* could be stocked at higher densities (Briggs et al. 2005).

Despite the absence of live shrimp introductions in the western hemisphere, WSSV eventually spread to the Americas. Early in 1999, WSSV was diagnosed as the cause of serious epizootics in Central American shrimp farms. In January 1999, WSSV first appeared in Panama and within 2 months the disease spread north to Honduras and Guatemala. By mid to late 1999, WSSV was causing major losses in Ecuador, then among the world's top producers of farmed shrimp. Exports of shrimp from Ecuador in 2000 and 2001 were down nearly 70 percent from pre-WSSV levels (Lightner 2003). It has been proposed that the introductions of WSSV to the Americas were the result of importation of frozen shrimp products from WSSV-affected areas of Asia and the value-added reprocessing of those frozen shrimp in coastal processing plants in the Americas (Nunan et al. 1998, Lightner 2003), or possibly through the use of imported frozen WSSV-infected shrimp as bait by sport fishermen (Hasson et al. 2006).

WSSV also reached Spain and Australia in 2000–01. In both cases, successful containment and eradication were reported and for both events, the importation and use of infected frozen shrimp as a fresh feed for broodstock were implicated as the route of introduction (Stentiford and Lightner 2011; OIE 2013).

In recent years WSSV spread to new areas of the world. In January 2011, shrimp farms in Saudi Arabia culturing *Fenneropenaeus indicus* began experiencing severe mortalities due to WSSV. In an attempt to determine the origins of the virus responsible for this outbreak, researchers at the University of Arizona (UAZ) analyzed the genotypes of the WSSV isolated from *F. indicus* in Saudi Arabia. They identified three different genotypes from different farms (Lightner 2012). Two of these differed from the strain of WSSV that originated in Asia and later spread to the Americas. The two Saudi Arabian WSSV genotypes differed from the Asian genotype by having a deletion of 1,522 base pairs from a specific section of the viral DNA (ORF 94); they differed from one another in the number of repeating base pair sequences in ORF 125 (Lightner 2012; Tang et al. 2012). The evidence suggests that the new genotypes found in Saudi Arabia may have originated in wild *F. indicus* broodstock from the Red Sea (Tang et al. 2012).

The shrimp industries in Mozambique and Madagascar remained free from WSD until September 2011 when a shrimp farm in Quelimane, Mozambique, experienced an outbreak of WSD. Since then, the shrimp industry in Mozambique has been virtually shut down. Eight months later, in May 2012, there was an outbreak of WSD in Madagascar at a farm north of Morondava. This farm has remained out of service since the outbreak occurred. Two other Malagasy shrimp farms were forced to perform emergency harvests and are virtually largely inactive as well.

Etiology

WSD is a lethal, contagious viral disease of penaeid shrimp and other decapod crustaceans. The causative agent of WSD is WSSV. WSSV is the only member of the genus Whispovirus, and family, Nimaviridae. WSSV is a large, enveloped, double-stranded DNA virus, measuring 80–120 nm in diameter and 250–380 nm in length (Durand et al. 1997). The virions are rod-shaped to elliptical in form, and have a unique flagella-like appendage at one end. The virions replicate inside the nuclei of infected cells without the production of occlusion bodies. WSSV targets tissues of ectodermal (cuticular epidermis, foregut and hindgut, gills and nervous tissues), and mesodermal (connective tissue, lymphoid organ, antennal gland, and hemopoietic tissue) origin (Wongteerasupaya et al. 1995).

Symptoms

WSD outbreaks in shrimp ponds are often accompanied by severe mortality. Acutely affected shrimp may be lethargic or anorexic and are often seen swimming erratically near the surface of the pond (Crockford 2008). WSD takes its name from the characteristic white spots on the carapace, although this is not necessarily seen in all infected shrimp. The white spots are due to deposition of calcium salts by the cuticular epidermis. Moribund shrimp frequently develop a pink to red discoloration. Mortality rates among populations of shrimp showing these signs may approach 100 percent within 3 to 10 days of the onset of clinical signs (Momoyama et al. 1994; Sangamaheswaran and Jeyaseelan 2001).

Transmission

WSSV can be transmitted either horizontally or vertically. Horizontal transmission occurs through the ingestion of infected tissues or organisms (Lo and Kou 1998; Durand and Lightner 2002) or by direct contact with an infected individual. However, consumption of infected tissue is more than 10 times as likely to result in

transmission of the virus as cohabitation with an infected individual (Lotz and Soto 2009). Vertical transmission from an infected female parent to her offspring has also been demonstrated (Lo et al. 1997).

Carriers

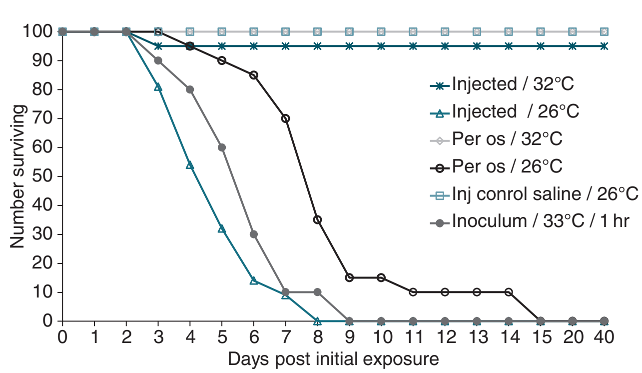
WSSV has a wide host range that includes virtually all decapod species and many other crustaceans (Lightner 1996; Flegal 1997; Lo and Kou 1998). All life stages may be infected, including eggs, larval stages and adults (Venegas et al. 1999). Many nondecapod crustaceans, such as copepods (Huang et al. 1995), isopods (Lo and Kou 1998; Overstreet et al. 2009), amphipods, and barnacles (Lei et al. 2002) have also been demonstrated to be carriers. It appears that WSSV infections in many of the non-decapod hosts are latent infections with no apparent pathology to the host (Lo and Kou 1998).

WSSV has also been found in several noncrustacean carriers. Polychaete worms have been demonstrated to carry WSSV and are capable of transmitting the virus to shrimp broodstock fed with infected worms (Vijayan et al. 2005; Desrina et al. 2012). WSSV can be found in the gills and digestive tracts of oysters in areas where WSSV is present (Vazquez-Boucard et al. 2010). Oysters have even been suggested to be sensitive bio-indicators of the presence of WSSV at low levels because they concentrate WSSV virions in their tissues (Vazquez-Boucard et al. 2010). Even marine algae (Liu et al. 2007) have been shown to carry WSSV.

Environmental Factors

Temperature has an important effect (figure 4.1) on the expression of disease in WSSV-infected *L. vannamei*. Vidal et al. (2001) found that

FIGURE 4.1: Effect of Hyperthermia on WSD in *L. vannamei* (After Vidal et. al 2001)



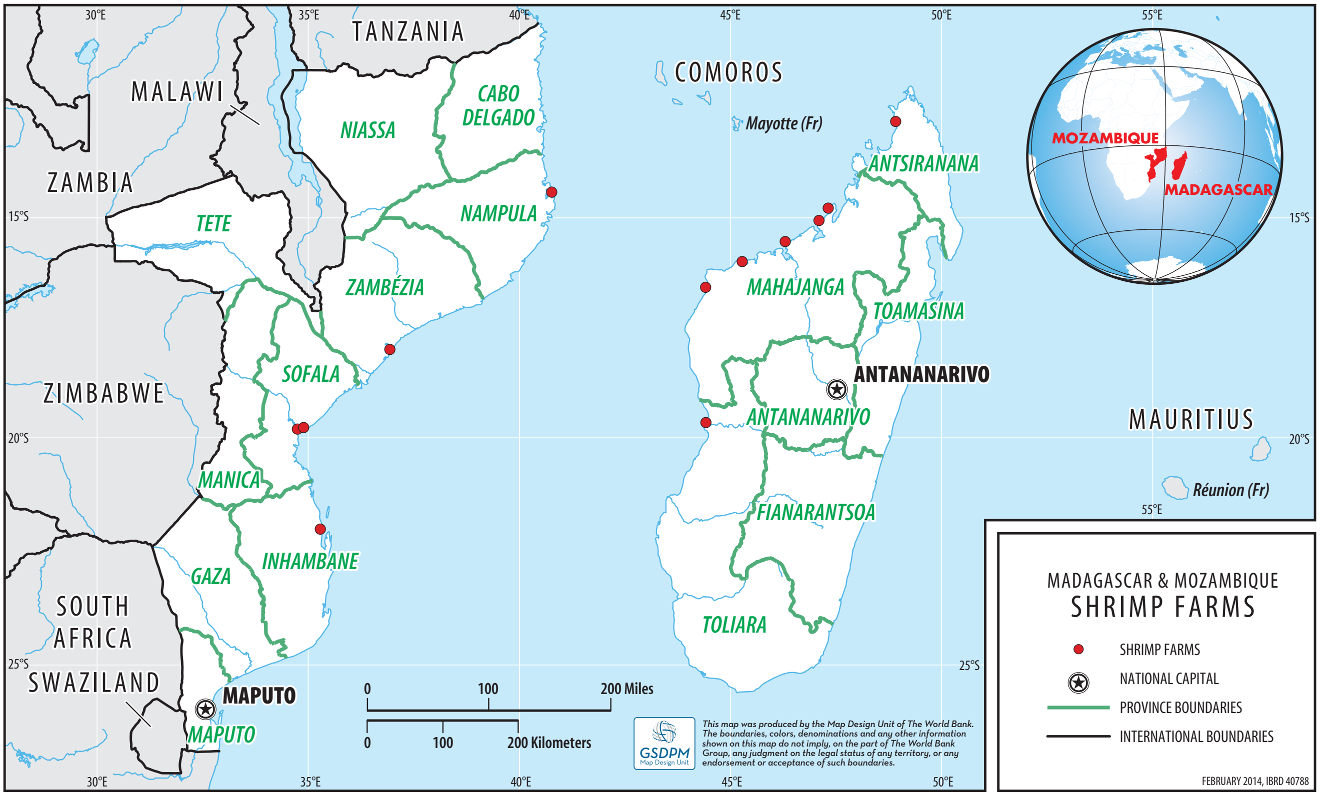
at temperatures above 32° C, WSD did not develop in WSSV-infected *L. vannamei*. However, when the same shrimp were cooled to 26°C, the disease would quickly develop with 100 percent mortality. Subsequent studies demonstrated that the hyperthermic phenomenon also occurred in other penaeids (Guan et al. 2003; Gunalan et al. 2010). Recent work has shown that replication of WSSV is significantly reduced or stopped under hyperthermic conditions (Du et al. 2006). These findings have helped to explain why WSD epizootics occur most often in the cooler seasons. In the Americas, that information has helped shrimp farmers manage WSD by avoiding stocking in the cool season or growing shrimp year-round in temperature-controlled greenhouses. Temperature fluctuations greater than ±3°C (Esparza-Leal et al. 2010; Tendencia and Verreth 2011) are also conducive to outbreaks of WSD. This appears to be due to the combined effect of a reduced host immune response and an increase in the rate of viral replication at temperatures less than 28°C (Moser et al. 2012). Heavy rainfall events may also precipitate outbreaks of WSSV due to the combined effect of a rapid drop in both salinity and temperature (Tendencia et al. 2010).

4.2 THE SHRIMP FARMING INDUSTRY ON THE MOZAMBIQUE CHANNEL

Shrimp farming along the Mozambique Channel began in 1989 with the construction of a pilot-scale shrimp farm in Madagascar that later developed into Aqualma, a large integrated operation that stimulated regional development of the sector (Le Groumellec et al. 2011). The industry is composed of a small number of commercial shrimp farms ranging in size from 174 to 800 ha. There are currently two industrial shrimp farms operating in Mozambique with a total production area of 534 ha and five industrial shrimp farms in Madagascar with a total production area of 2,300 ha. Unlike many regions where shrimp farms are highly concentrated in a small area, the farms in Madagascar and Mozambique are widely separated geographically (figure 3.2).

Shrimp farming in the region is based on the rearing of black tiger shrimp (*P. monodon*) in semi-intensive earthen ponds of 2–10 ha. Most ponds are stocked at relatively low densities (7–12 shrimp/m^2) with target production levels of 1.5–2.2 tons/ha (Le Groumellec et al. 2011). The ponds are managed as flow-through systems, with water exchange rates as high as 20 percent per day. Little aeration is employed. Pond

FIGURE 4.2: Major Shrimp Farming Installations along the Mozambique Channel



temperatures generally remain above 28°C from October to April, but during the colder winter months (June to August) temperatures can drop as low as 22°C. Because of this, some farms in the region harvest before the coldest months of the year, and produce just two crops per year. However, the largest farms in Madagascar operate year-round, producing 2.3–2.5 crops per year. The summer months of December to April are the wettest months and pond salinities often drop below 10 ppt during this period. The winter months are the driest months, and pond salinities in some areas rise above 35 ppt.

Production costs for shrimp farms in Madagascar and Mozambique are higher than in most other areas of the world due to the isolation of the individual farms and the logistics of doing business in remote areas (Le Groumellec et al. 2011). In Madagascar, all electricity must be generated on site and the cost per kw-hr is high. Because of the high production costs, the product must be sold at premium prices. The shrimp farms in the Mozambique Channel region focus on producing high quality head-on shrimp for the European market. Many of the companies market their shrimp as organic or environmentally sustainable products. The farms in the region have successfully developed a unique identity for Madagascar and Mozambique shrimp in the European markets as a premium quality product. The farms in this region are all vertically integrated, each with its own hatchery and processing plant.

By virtue of its isolation, the Mozambique Channel shrimp industry was the only major shrimp farming region in the world that had never had a diagnosed case of any World Organization for Animal Health (OIE)-listed shrimp diseases prior to 2011.

The Mozambique Shrimp Farming Industry

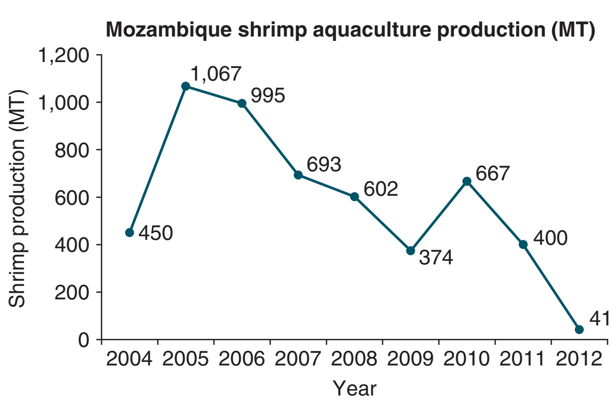
The shrimp industry in Mozambique is small, with only two industrial shrimp farms currently in operation. The total production area in these two farms is only 534 ha. However, there is significant potential for further development. The Ministry of Fisheries recently surveyed coastal land in the country and concluded that there are 30,000 ha suitable for development of industrial shrimp farms (Omar and Hecht 2011).

The first industrial shrimp farm in Mozambique was built in 1994. By 2004 there were three large shrimp farms operating in the country. Production from these farms (figure 4.3) peaked in 2006 at 1,067 metric tons per year (Blanc 2012). In 2007 the largest farm, Indian Ocean Aquaculture, shut down due to technical and financial difficulties. Low market prices limited production output in 2008 and 2009 and one of the remaining shrimp farms suspended production for a period in 2010 when the farm was sold. Productivity was beginning to increase when WSSV hit the country in August 2011. In 2012, aquaculture shrimp production in Mozambique dropped to 41.4 MT.

Of the two currently active commercial shrimp farms in Mozambique, the oldest (1994) and largest farm (350 ha) is Aquapesca, located near the town of Quelimane in Zambezia Province. The grow-out ponds at Aquapesca are mostly 10 ha earthen ponds that are stocked at low densities (7/m^2). There are two production cycles per year, with a 2-month dry-out period from June to July. Annual production prior to 2011 was 600–800 MT/yr. Postlarvae for stocking the farm are produced at their hatchery facility in Nacala. The majority of the broodstock for this hatchery are wild-caught. Aquapesca markets their shrimp as a head-on organic product, and the organic standards require that within 3 years of obtaining organic certification, 50 percent of the broodstock must be domesticated. To comply with this requirement, in 2009 Aquapesca began to select some of their broodstock from the grow-out ponds. There are no specific pathogen-free broodstock available in Mozambique.

Prior to the WSSV outbreak in 2011, the Aquapesca risk management plan called for each batch of postlarvae stocked at the farm to be polymerase chain reaction (PCR)-tested for OIE listed viruses (WSSV, Monodon baculovirus [MBV], yellowhead virus [YHV]/gill-associated virus [GAV], Taura syndrome virus (TSV), infectious myonecrosis disease (IMNV), infectious hypodermal and haematopoetic necrosis/virus (IHHN/V). Aquapesca also tested 30 percent of the broodstock brought into their hatchery.

FIGURE 4.3: Mozambique Shrimp Aquaculture Production, 2004–12 (Sibeni and Calderini 2014)



The other industrial shrimp farm in Mozambique is Sol y Mar, located near Beira. This farm consists of 58 3-ha grow-out ponds and two large reservoir ponds (100 ha total area). Like Aquapesca, the Sol y Mar farm is stocked at low density (7–10/ha). The facility includes a hatchery that is operated when PLs are needed for stocking. The broodstock are wild-caught. Prior to 2010, the Sol y Mar farm was operated continuously, achieving 2.5 production cycles per year. In 2010 the farm was shut down and put up for sale. It was purchased by a Chinese company and was undergoing renovations when the outbreak of white spot disease occurred at the Aquapesca facility in September 2011.

The majority of the wild-caught *P. monodon* broodstock used by the farms in Mozambique are supplied by Marbar Lda. Marbar has been in operation since 1997 and collects approximately 7,000 breeders per year. About one-third of the shrimp collected are sold to Mozambique shrimp farms. The rest are sold to hatcheries in Asia, mostly in Vietnam and Malaysia. The broodstock collection season extends from March to the end of November. Marbar has a multi-step process for acclimating broodstock and preparing them for shipment to the hatcheries. Adult-size shrimp are collected either from Beira in the north or Vilankulos in the south. After capture, the broodstock are held in a small-scale quarantine system for several days near the collection site. If no abnormalities or unusual mortality is noted, the shrimp are then moved to one of two recirculating conditioning facilities, either in Beira or Vilankulos. In the conditioning facility, the shrimp are treated with antibiotics and fed with fresh clams and squid. Prior to 2012, samples were occasionally sent to UAZ for histology or PCR analyses. In 2012, Marbar began conducting their own PCR analyses, testing for WSSV, MBV, and hepatopancreatic parvovirus (HPV). Only a small percentage of the animals collected are tested, however, due to the high cost. The company relies primarily on a stress-testing procedure to screen for healthy animals.

The Shrimp Producers Association of Mozambique (Associação de Produtores de Camarão de Moçambique; APCM) is a shrimp

producer's advocacy group with representation from both of the shrimp farms in Mozambique, Marbar, and the Centro de Biotechnología. The APCM functions as the interface between the private shrimp producers and the public sector. The association represents the shrimp farms in discussions with the government regarding policies, regulation, and biosecurity. In 2009, the APCM received €1.5 million in funding from the French Ministry of Economy and Finance and the French Development Agency (AFD). The funding was part of a Trade Capacity Building Program (PRCC) with the goal of improving the international competitiveness of the Mozambique shrimp farming industry. Mr. Blanc was hired by the APCM to administer this project. After the WSSV outbreak in Mozambique, the PRCC funds were redirected toward funding of a WSSV surveillance program and helping to manage the crisis. One of the key objectives for the PRCC is to help strengthen the capacities of Instituto Nacional de Inspeccíon Pesquera (INIP) as the Competent Authority for Aquatic Animal Health. The APCM is planning to provide training for technicians at the Centro de Biotechnología and INIP's Central Veterinary Laboratory to help them develop the capacity as Aquatic Animal Health (AAH) Reference Laboratories. Representing the APCM, Mr. Blanc has played a key role in managing the response of Mozambique to the WSSV crisis.

The Ministry of Fisheries has overall responsibility for the management and administration of aquaculture in Mozambique. Two government bodies deal directly with aquaculture: the Instituto Nacional de Desenvolvimento da Aquacultura (INAQUA), and the INIP.

INAQUA is a new agency that was created in 2008 by Decree No. 28/2008. INAQUA is the designated lead agency for all government projects related to aquaculture. It is responsible for strategic planning for aquaculture policy and for proposing legislation and regulations pertaining to aquaculture. It also is responsible for managing aquaculture licenses and authorizations for commercial projects. INAQUA conducts surveys and statistical analyses related to the Mozambique aquaculture sector. Prior to the outbreak, there was no formal national policy on aquatic animal health. INAQUA is now taking the lead role in developing a national policy to address aquatic animal health issues.

INIP is the agency responsible for control of quality standards for all fisheries products. INIP is the designated Competent Authority for food safety and in March 2012 INIP was designated as the OIE National Focal Point for Aquatic Animal Health for Mozambique. While the INIP team members are well-trained in HACCP, quality control, and seafood safety, they do not have the training or equipment to serve as an Aquatic Animal Health Reference Laboratory. While INIP personnel are anxious to acquire the expertise necessary to take a more active role in aquatic animal health management, at present there is no legislation in Mozambique to provide a legal framework or funding for these activities. In Mozambique the Veterinary Authority is under the Ministry of Agriculture and INIP, the Competent Authority for aquatic animal health, is under the Ministry of Fisheries. This arrangement creates some challenges for the coordination between veterinary and fisheries authorities (Baloi et al. 2011).

Aquatic Animal Health Laboratories are available, though there is no official government-designated laboratory for AAH services. In-country diagnostic work for the shrimp farms is carried out by the Centro de Biotechnología, a laboratory at the Universidade Eduardo Mondlane. The Centro de Biotechnología (CB-UEM) laboratory is a research and diagnostic laboratory shared by multiple departments at UEM. The laboratory began conducting PCR analyses on shrimp in 2008. They use IQ2000 PCR kits and can test for WSSV, IHHNV, MBV, TSV, IMNV, YHV/GAV, and HPV. The tests cost US$10/sample. The lab has a capability of processing 10 samples/day or 40 samples per week. Prior to the WSSV outbreak in 2011 the CB-UEM only tested about 150 samples per year for the shrimp industry. Most of the samples tested were postlarvae or broodstock pleopods submitted by the Aquapesca farm. Any positive test results are reported to the Ministry of Fisheries.

Histological work and PCR analyses on shrimp with suspected diseases are usually performed by the OIE Reference Laboratory located at the University of Arizona. Some samples are also sent to other international diagnostic laboratories, such as the Concepto Azul laboratory in Ecuador.

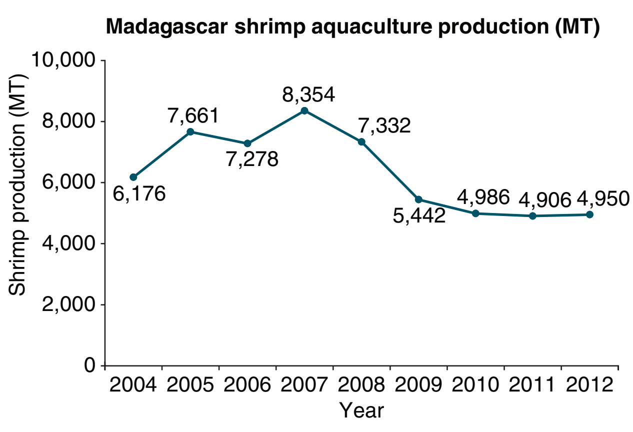
4.3 THE MADAGASCAR SHRIMP FARMING INDUSTRY

Commercial shrimp farming began in Madagascar in the early 1990s with the establishment of the Aqualma shrimp farm on Mahajanga Bay on the west coast. Within 10 years the industry had expanded to six farms and an annual production of nearly 6,000 MT per year. Annual production peaked at 8,354 MT/year in 2007

(figure 4.4). However, production declined over the next several years due to a combination of rising production costs associated with higher fuel and falling shrimp prices, the latter due to increased production in Latin America and Asia. In 2009, the difficult economic conditions resulted in the closure of two shrimp farms. One of these, Unima's Marima shrimp farm, reopened in 2012 with the return of more favorable market conditions. Currently, there are four shrimp farming companies in the country operating five farms with a total production area of 2,300 ha.

The two largest shrimp farms in Madagascar are both owned by the Unima group. The oldest and largest farm is the Aqualma farm in Mahajanga, with a total production area of just under 800 ha. The second Unima shrimp farm is the 450-ha Marima shrimp farm, located in Besalampy. The Unima group operates a larval rearing facility in Mifuko, and leases a government hatchery in Mahajanga to increase their larval-rearing capacity. They also operate a separate breeding center in Moramba. Unima initiated a broodstock domestication program in 2000 to eliminate their dependence on wild broodstock. Since 2003, 100 percent of the postlarvae stocked in Unima ponds were derived from captive-bred SPF broodstock. In addition to screening their broodstock for OIE-listed pathogens, they also screen for some local pathogens, including two species of microsporidians, a Rickettsia-like intracellular bacteria, an iridovirus, and a local form of Monodon slow growth syndrome. The Unima group markets their shrimp in the European Union (EU) as a premium head-on product. In 2004, Unima obtained the "Label Rouge"

FIGURE 4.4: Madagascar Shrimp Aquaculture Production, 2004–2012 (Sibeni & Calderini 2014).



for their shrimp from France's Ministry of Agriculture, certifying the superior quality of the product.

Unima's Marima shrimp farm was the second shrimp farm in Madagascar to be infected by WSSV in September 2012. The farm conducted an emergency harvest when WSSV was detected in wild crustacean populations near the farm and was able to sell much of what they harvested. They have restocked at very low densities using SPF PLs. The Aqualma farm has not been infected by WSSV. The Unima group, which conducts their own PCR testing, is engaged in a large-scale surveillance program to monitor the incidence of WSSV in wild crustacean populations on the west coast of Madagascar. The objective is to provide an early warning of the spread of WSSV in the wild before it reaches Mahajanga Bay.

The third largest shrimp farm in Madagascar is Oso Farming–Les Gambas de l'Ankarana (LGA). This farm is a subsidiary of R&O Seafood Gastronomy, headquartered in Paris. R&O Seafood Gastronomy is France's largest seafood distributor. LGA, located near the northwestern tip of the island, operates 42 grow-out ponds with a total water surface area of just over 400 ha. The LGA farm is organically certified under the French AB-Bio label and EU Regulation 710-2009, which specifies standards for organic aquaculture products. Shrimp are stocked at a density of 11 shrimp/m^2 and grown to an average harvest size of 23 grams in approximately 150 days. Two crops per year are harvested with a 39-day dry-out period between crops. In keeping with organic standards, the ponds are not routinely aerated. Daily exchange rates peak at 20 percent of pond volume per day. LGA also stocks SPF postlarvae produced at their own breeding center. Broodstock are reared in specialized broodstock rearing ponds. The breeding center is reported to be capable of producing up to 5,000 broodstock every 2 months. LGA has a well-equipped laboratory with microbiology and PCR-testing capabilities. The lab can process up to 178 samples per day. No WSSV has been detected to date at the LGA facility or in nearby areas. However, the company has devoted considerable resources to surveillance of wild crustacean populations in near shore waters from the northern tip of Madagascar south to Mahajanga. In the 12-month period from May 2012 to April 2013 the company has processed over 37,000 PCR samples.

The Aquamen EF farm at Tsangajoly is located north of Morondava, and is the southernmost shrimp farm in Madagascar. The Aquamen farm consists of 110 ponds with a total water surface area of 400-ha. The production ponds average 3.6 ha in area. Like all the farms in the region, the Aquamen facility is vertically integrated, with a hatchery and processing plant. The Aquamen hatchery does not have an SPF breeding center, instead relying on wild broodstock. In April 2012 the Aquamen farm became the first farm in Madagascar to be infected with WSSV. The farm was shut down and disinfected, but has not yet been permitted to restock, pending submission and approval of a biosecurity plan.

The smallest farm in Madagascar is the 251-ha Aquamas farm, located in Soalala, 150 km south of Majajanga. This farm consists of 142 ponds ranging in size from 0.6–2.7 ha. Like the Aquamen hatchery, the Aquamas hatchery utilizes wild *P. monodon* broodstock. These broodstock are not screened for viruses, but each batch of postlarvae is PCR-tested at the time of stocking. The testing is performed by the Pasteur Institute laboratory in Antananarivo. Since the outbreak of WSSV, the Aquamas facility has been experimenting with various management strategies to improve biosecurity, including chlorination of the water in their supply canal and filtering the seawater through 250 micron screens installed in specially constructed concrete gates located at the head of the secondary supply canals. Only nine grow-out ponds with a total area of about 25 ha have been stocked as part of the trial production runs with this new system.

The Madagascan shrimp industry is based on semi-intensive production of *P. monodon* in 5–10 ha earthen ponds with little or no aeration. The ponds are managed as flow-through systems with water exchange rates peaking at about 15 percent of pond volume per day. Stocking rates are generally less than 12/m^2; average weight at harvest ranges from 20 to 30 grams; yields average 1.5 to 1.8 T/ha. Most of the farms produce two crops per year with a dry-out period between crops during the coldest months. The largest farm, however, operates on a continuous basis, obtaining 2.3 production cycles per year.

All of the farms in Madagascar are vertically integrated, with their own hatchery and processing plant. Unima and Oso Farms have developed SPF breeding programs and no longer rely on wild broodstock. The smaller companies use wild broodstock.

The Association of Shrimp Farmers and Fishers of Madagascar (GAPCM) is an advocacy group composed of both shrimp farmers and shrimp fishermen. The GAPCM was initially organized as an association of shrimp fishing boat operators in 1994, but its membership was expanded in 2001 to include shrimp farmers. The GAPCM has a total of 16 members, divided into two divisions: a shrimp fishing division with 11 members, and a shrimp aquaculture division with five members. Each of the shrimp farms in the country is represented in the GAPCM. The stated objectives for the association are to influence the development of rational policies for managing and regulating the shrimp farming and fishing sectors in the country, to represent the shrimp industry in discussions with the government, and to defend the common interests of its members. The GAPCM works closely with and has received funding from its institutional partners, including the line ministry responsible for fisheries, and the French Development Agency. The GAPCM has also forged a partnership with the World Wide Fund for Nature (WWF) to promote sustainable shrimp farming practices that promote resource conservation and preservation of biodiversity.

While the stated goal of the GAPCM is to serve as the unified voice for the shrimp aquaculture industry, in practice the GAPCM is not a unified group. Within the group there are deep divisions and lack of trust due to a long-standing rivalry between the group's two most powerful and influential members: Unima and Oso Farming. The lack of unity within the GAPCM has the potential to interfere with its effectiveness and ability to develop a coordinated and cooperative response to the WSSV.

The Ministry of Fisheries and Marine Resources (Minestere de la Peche et des Ressources Halieutiques; MPRH) is the agency with overall responsibility for the aquaculture sector in Madagascar. Within the MPRH the Directorate for Aquaculture is responsible for strategic planning for the aquaculture sector and for issuing aquaculture licenses and for proposing legislation and regulations for the aquaculture sector.

The Autorite Sanitaire Halieutique (ASH) is the Competent Authority for seafood certification and veterinary inspection in Madagascar. ASH is also the designated OIE National Focal Point for Aquatic Animal Health in Madagascar.

Like INIP in Mozambique, ASH is the agency responsible for control of quality standards for all fisheries products. Unlike the situation in Mozambique, the legal framework for AAH policy in Madagascar is much better defined. In 2001, the legislature passed the Development of Responsible Shrimp Aquaculture Act (Act 2001.020) which established a permitting process and prescribed basic biosecurity and environmental protection practices to be followed by the industry. In 2005, Decree No. 2005-185 established a National Pathogen List for animal diseases.

The Laboratory for Epidemiological Surveillance (LES) came into existence through a 2006 convention between the GAPCM, the Malagasy government, and the French Development Agency and identified shrimp disease outbreaks as one of the most important risk factors for the future development of the shrimp aquaculture industry in Madagascar. The convention called for a national policy on aquatic health, an aquatic disease surveillance program and the establishment of a national aquatic animal health laboratory. After the convention, the government issued Decree No. 20142/2006 and with €1.4 million from AFD, created the Laboratory for Epidemiological Surveillance at the Pasteur Institute in Antananarivo. In 2010, LES was designated by the government as the official national laboratory for aquatic animal health monitoring.

In 2009, Decree No. 33423 established a National Policy on Aquatic Health. As part of this national policy, a shrimp disease survey was commissioned for the west coast of Madagascar. The plan called for sampling of wild and farmed shrimp by ASH personnel and PCR analyses by the LES. One of the original objectives of the lab was to survey diseases in the region to establish it as an OIE disease-free zone. Aquamen volunteered to be the first farm sampled in the survey. The disease survey began in 2010 with samples being taken both from wild crustaceans at various locations on the west coast of Madagascar and at the Aquamen farm. The sampling program was designed to detect viral diseases at a 1 percent incidence rate in the population. No WSSV was detected in 2010 or 2011. Funding from the AFD ended after 2010, and in 2011 government funding for the project also lapsed. Sampling was discontinued in 2012 due to insufficient funds.

Since the WSSV outbreak began, the LES has not been an active participant in the WSSV surveillance efforts in Madagascar. This is only partly due to the lack of funding for this work. Other factors limiting their involvement include the lack of staffing to collect samples, and restrictions on reporting results to the farms of samples they submitted. The current rules require that all results must be reported first to ASH. This results in a time delay of about 3 weeks in reporting results back to the farms. Also, the cost per sample for PCR testing at the LES (US$60/sample) is high, which is a significant deterrent for farms to use the LES for routine testing. Unima and LGA do their own PCR testing at a cost of US$10/sample or less, rather than use the LES laboratory.

4.4 THE WSD OUTBREAK ON THE MOZAMBIQUE CHANNEL

Soon after WSSV appeared in Saudi Arabia, it began showing up in the Mozambique Channel. In September 2011 WSSV was diagnosed at the Aquapesca shrimp farm in Mozambique. In April 2012 WSSV was found at the Aquamen EF farm in Madagascar. In September 2012 WSSV was found at the Marima farm in Besalampy. The genotypes of the WSSV isolated from the Aquapesca farm in Mozambique and at the Besalampy farm in Madagascar were the same as one of the new WSSV strains found in Saudi Arabia. The genotype of WSSV isolated from the Aquamen farm was identical to the other new WSSV strain from Saudi Arabia (Lightner 2012). These results suggest that both strains of WSSV found in the Mozambique Channel have a common origin with the Saudi Arabian WSSV strains. It is not clear how the Saudi Arabian WSSV was transported to the Mozambique Channel. It could have been transported by ocean currents or in ship ballast water. It is also possible that WSSV-infected shrimp from Saudi Arabia were processed in shrimp processing facilities in Mozambique or Madagascar. Shrimp processing waste is a suspected route for introduction of WSSV into the Americas (Durand et al. 2000).

WSSV in Mozambique

The following is a brief description of WSSV outbreak in Mozambique and the actions that were taken by the various stakeholders.

The first outbreak of WSD occurred at the Aquapesca shrimp farm in Quelimane. Following a significant temperature drop (>3°C), mortalities and moribund shrimp were observed in one pond and

in the water inlet canal. The pleopod samples of moribund shrimp were sent to the Centro de Biotecnología da Universidad Eduardo Mondlane for PCR analysis. On September 3, CB-UEM reported the samples tested negative for WSSV and all other OIE-listed diseases, despite the fact that the shrimp that were sampled had visible white spots on the carapace (Le Groumellec 2011). There is some evidence that the samples had been fixed in Davidson's fixative rather than 95 percent ethanol. This would explain the negative PCR result. Unfortunately, the error allowed the disease to spread for another 10 days before it was properly diagnosed.

On September 3, managers began flushing the inlet canal. Believing the disease to be bacterial in origin, the managers began feeding the shrimp with medicated (oxytetracycline; OTC) feed. However, by September 5 two-thirds of the ponds on the farm were affected. INAQUA was notified of the disease outbreak on September 4.

On September 5 representatives from INAQUA and INIP (the OIE focal point for AAH) visited the shrimp farm to observe the problem firsthand. Pleopod samples collected on September 4 and 5 were sent to the UAZ OIE Reference Laboratory with a request that they be tested for Rickettsia-like bacteria (RLB). Despite the white spots on the shrimp, WSSV was discounted as a possible cause due to the negative PCR result from September 3. Additional samples were sent to CB-UEM. On September 9, UAZ reported the samples tested negative for RLB. Meanwhile, WSD continued to spread on the farm and mortalities were mounting. The inlet canal continued to be flushed daily. On September 12 the farm managers requested the UAZ and CB-UEM laboratories to test the samples sent on September 6 for WSSV. Later that day UAZ confirmed the samples were positive for WSSV. Flushing of the inlet canal was stopped immediately. CB-UEM confirmed the diagnosis on September 14 and 16.

Destruction of the shrimp and disinfection of the Aquapesca farm was carried out between September 16 and 29 under the supervision of representatives from INIP. The OIE was notified of the presence of white spot disease in Mozambique on September 22 by the National Director of Veterinary Services.

WSSV hit the Aquapesca hatchery in Nacala at almost the same time as the farm was hit. On September 4, 2011, mortalities were observed among broodstock that had been captured from the Moma area and brought to the hatchery on September 3. The shrimp turned reddish, had difficulty molting, and then died. Handling stress was suspected. However, the mortalities continued until 100 percent of the shrimp had died. At least two new batches of broodstock from the Moma area were received at the hatchery over the next several days. These, too, developed the same symptoms and began dying. By September 18 broodstock that had been in the hatchery since early August and were housed in a different area in the hatchery also began dying.

On September 17 and 20 samples were collected from all broodstock groups at the hatchery and were sent to a private laboratory in Ecuador (Concepto Azul) for PCR testing. Results were not received back from this laboratory until October 27, November 5, and November 8. All samples were positive for WSSV.

The laboratory operated normally despite the mortalities until September 29, 2011, when the hatchery was inspected by INIP and INAQUA. The destruction of all stocks was ordered and initiated immediately.

On November 20, 2011, a shipment of wild shrimp captured from the Nova Mambone area were brought to Marbar's Vilankulos facility where they began exhibiting clinical signs of WSD. These shrimp were quarantined and pleopod samples were taken and sent to the CB-UEM and UAZ laboratories for PCR analysis. Three additional batches of shrimp from the same area were brought to the facility over the next 2 weeks that also developed symptoms of WSD. On December 9 and 10 UAZ and CB-UEM both reported positive WSSV PCR results. The Competent Authority was notified, and the quarantined shrimp were destroyed under the supervision of INIP. Curiously, none of the shrimp at the facility other than the quarantined shrimp from Nova Mambone were tested. Nor did INIP request PCR testing of shrimp held at Marbar's Beira facility.

Following the WSSV outbreaks, Marbar has continued to collect wild broodstock and sell them to hatcheries in Asia after on-site testing using an IQ+ PCR diagnostic kit purchased for the company by the APCM. They prefer to perform their own testing due to the high cost (US$20/sample) of PCR testing at CB-UEM. However, they only test shrimp they suspect of being infected after subjecting them to a

stress test involving exposure to low temperature and dissolved oxygen. Shrimp that appear weak or which have reddish coloration or necrotic lesions are selected for PCR testing. About 10 percent of the shrimp that test positive to WSSV survive the stress tests. Dr. Chris Schnell, Technical Director at Marbar, believes this is evidence that the surviving shrimp may be resistant to WSSV.

The Sol y Mar shrimp farm in Beira was not in operation at the time WSD hit the Aquapesca farm. However, Sol y Mar stocked their farm three times in 2012, and each time the farm experienced major losses due to WSD. After stocking the farm in March, there was a period of heavy rainfall and cool temperatures in April. Soon after that, there was an outbreak of WSD causing 100 percent loss of the crop. The farm was drained, disinfected, and dried out over the winter months of May to September. In October and November, the farm was restocked, but soon experienced major mortalities due to WSD. The farm was dried out and restocked again in December. Although WSD disease again hit the farm, this time there were several ponds that did not have WSD outbreaks. The improved results may have been due to the warmer, drier weather conditions during this crop cycle.

Sol y Mar conducts its own PCR analyses on-site using an IQ+ detection kit. No shrimp samples were submitted to the UAZ or CB-UEM laboratories for PCR analysis. INIP did not supervise the destruction of shrimp stocks following the outbreaks, or inspect the farm prior to restocking.

Sol y Mar operates a small hatchery on-site using wild broodstock purchased from local fishermen. Samples of their broodstock are PCR-tested prior to use. Despite the negative PCR test results, the broodstock may still have been the original source of the WSSV outbreak in March. Often shrimp with low levels of infection will test negative for WSSV prior to spawning, but test positive afterwards (Hsu et al. 1999). None of the broodstock was retested after spawning. After the March outbreak, WSSV may well have survived in populations of ghost shrimp and crabs on the farm, resulting in rapid infection of shrimp after restocking of the farm.

Following the disinfection and dry-out of the farm and hatchery, Aquapesca set up a broodstock quarantine and PCR screening program at the Nacala hatchery. When wild broodstock are brought to the hatchery they are placed in individual holding tanks in a dedicated quarantine greenhouse. Pleopods are taken from each shrimp for PCR testing. Only shrimp with negative PCR test results are transferred to the maturation building. Broodstock are not, however, retested after spawning.

Aquapesca cautiously restocked the farm early in 2012 using PLs produced from the PCR-tested broodstock. Initially they ran a small-scale trial for only 2 months. Survival was 90 percent. Encouraged by the success of this trial they restocked the entire farm for the second cycle. Many of the ponds were again hit by WSD, and overall survival for the crop was less than 1 percent.

WSSV in Madagascar

The following account of the WSSV crisis in Madagascar is based on interviews with public sector stakeholders, including Dr. Luc Josué Ralaimarindaza, Executive Director of the Autorité Sanitaire Halieutique, Dr. Iony Razanajatovo, Director of the Laboratory for Epidemiological Surveillance, and with private stakeholders, including representatives from the Unima group, Oso Farming LGA, and Aquamas.

The first farm in Madagascar to develop WSD was the Aquamen EF shrimp farm, located north of Morondava. On April 10, 2012, the Aquamen farm became the first farm in Madagascar to be infected with WSSV. Approximately 4 months before WSSV was detected at the farm the LES suspended the surveillance program at Aquamen and surrounding areas due to lack of funding. This was unfortunate because it deprived Aquamen of an early warning that might have allowed them to take measures to prevent or mitigate the effects of WSSV on the farm. Shortly after mortalities were observed on the farm, the shrimp population on the farm was sampled and tested for WSSV. Prevalence of WSSV-infected animals was 10 percent. At the same time the prevalence in wild populations of shrimp near the farm was 5 percent. It was also reported (L Ralaimarindaza, personal communication) that WSSV was not detected along the coast except in the immediate vicinity of the Aquamen farm. It is not clear when these prevalence data became available as there was not an ongoing surveillance program in effect in May 2012. Mortalities increased and within 2 weeks about 75 percent of the shrimp on the farm were dead. The

UAZ reference laboratory officially confirmed the WSSV diagnosis on May 9, 2012.

The Competent Authority ordered Aquamen to destroy all shrimp on the farm without releasing water from the ponds. Aquamen was also ordered to shut down their hatchery and destroy all broodstock and seedstock. On April 21 Aquamen began collecting and burying the remaining shrimp on their farm. They stopped pumping, closed the discharge gates, and held the water in their ponds for 3 months until it had evaporated. The ponds and canals were then plowed, limed, and dried out. Over 1 year later Aquamen remains closed, because the regulatory policy of the Competent Authority does not permit restocking until an approved biosecurity plan has been submitted by Aquamen.

In September 2012 the Marima shrimp farm in Besalampy was the next farm to experience an outbreak of WSD. In early September, Unima's own surveillance program collected some wild shrimp from near the Marima pump intake that tested positive for WSSV. Following their contingency plan, Marima stopped all pumping at the farm and began emergency harvesting of the ponds. All ponds were harvested within 2 weeks. PCR-testing of shrimp within the farm showed that some of the ponds were infected with WSSV, but most of the ponds were salvaged. The Marima ponds were dried and disinfected and a biosecurity plan was prepared and submitted to the Competent Authority. The plan was approved and the ponds were restocked after the dry-out period.

The Aquamas shrimp farm is located less than 150 km to the north of Marima. WSSV was detected on the Aquamas shrimp farm 1 month after it was found at Marima. Aquamas immediately initiated an emergency harvest of all their ponds. Aquamas dried out the facility for 5 months before stocking nine ponds in March 2013 to test the effectiveness of some biosecurity enhancements to the farm.

As of May 2013 neither the Aqualma farm nor the Oso Farming LGA farm have been affected by WSSV. Surveillance of wild shrimp populations has yet to detect WSSV within Mahajanga Bay where Aqualma is located. The Oso Farming LGA farm is located nearly 500 km to the north of Mahajanga. WSSV has not been detected north of Mahajanga.

4.5 MANAGEMENT OF WSSV OUTBREAKS WORLDWIDE

WSSV is the most serious pathogen of cultured shrimp. Beginning in the 1990s, almost all shrimp producing countries in Asia and nine countries in the Americas have been infected as of 1999. Most recent outbreaks include that of Brazil (2005), the Kingdom of Saudi Arabia (2010–11), Mozambique (2011), Brunei (2012), and Madagascar (2012). Losses from the 1992–93 WSSV outbreaks in Asia alone were estimated at US$6 billion; in the Americas, about US$1–2 billion during the 1999 outbreak.

The path to recovery has not been the same for Asia and Latin America. The production strategies that predominate in these two regions have always differed. In Asia, shrimp ponds are typically 1 ha or less and stocked at densities of 50–120 shrimp/m^2. Ponds are aerated continuously and water exchange rates are low. Latin American farms typically consist of earthen ponds averaging 2–10 ha and stocked at densities of 20/m^2 or less. Latin American farms use little aeration but water exchange rates of 10–15 percent/day are common. The differences in farm design and production strategy have led to different approaches to managing WSD.

The Asian WSSV Management Approach

In Asia, the approach to managing WSSV is to eliminate all potential sources of infection. Vertical transmission is prevented by stocking SPF postlarvae. Prevention of horizontal transmission requires a variety of measures. By increasing the amount of aeration in the shrimp ponds, water exchange can be largely eliminated (Hopkins et al. 1993). Each kW of aeration can support an additional 500 kg of shrimp production (Boyd 1998). Shrimp ponds in Asia often have between 10 and 20 kW/Ha of aeration, allowing them to produce 5–10 MT/Ha of shrimp with little or no water exchange. The low rates of water exchange significantly reduce the risk of introducing carriers of WSSV into the shrimp ponds. The low volume of exchange also allows for economical disinfection of the water that is pumped into the farm. After filling a pond for stocking, most Asian farms treat the water with either chorine (20–30 ppm) or a crustacide (for example, Trichlorfon) to kill the crustacean carriers of WSSV. Many also utilize dedicated treatment ponds to treat water used for exchange with chlorine or crustacides.

The Latin American WSSV Management Approach

The strategy of heavily aerating ponds and eliminating water exchange is not a practical strategy in Latin America, where ponds are often 10 ha or larger. In Latin America the strategy adopted included stocking only SPF PLs, operating only during the warm months of the year, improved filtration (200 microns) of incoming water, and better management of pond bottoms and water quality. As a long-term strategy, several of the larger farms invested in breeding programs in an effort to develop shrimp stocks with significant resistance to WSSV.

4.6 FARM-LEVEL STRATEGIES FOR CONTROLLING WSSV

Avoid Stocking during the Cold Season

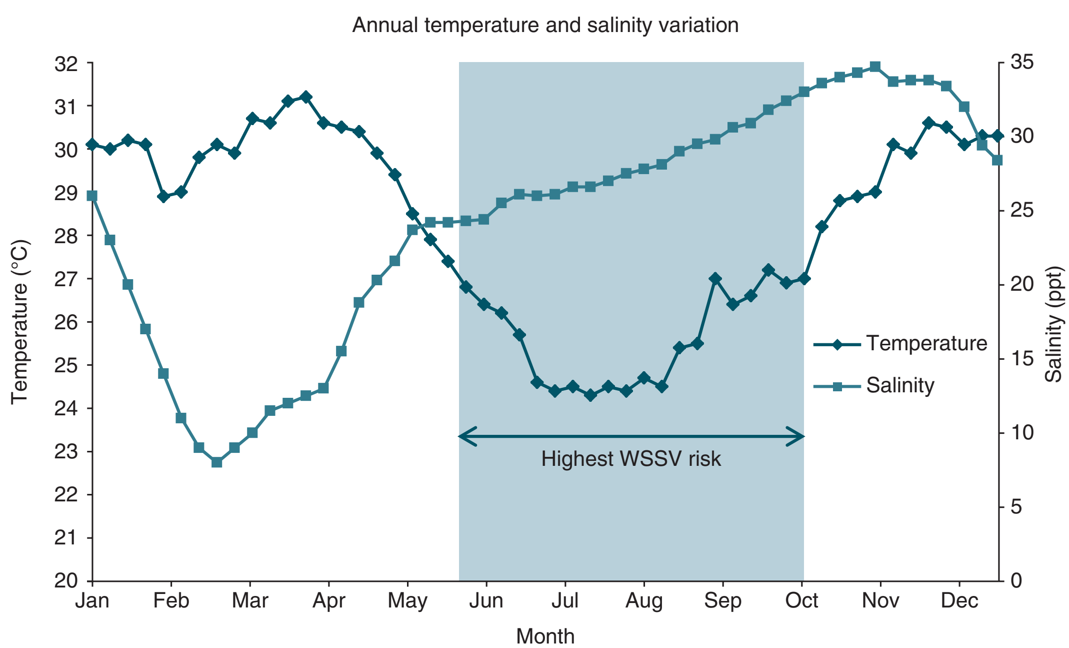
The expression of WSSV infections in shrimp are temperature dependent. High water temperature (>32°C) prevents the onset of WSD and significantly reduces mortality of WSSV-infected shrimp (Vidal et al. 2001). WSSV infection is much more likely to cause mortality when water temperatures are 27°C or less. Because of this relationship between water temperature and WSSV virulence, many shrimp farmers in areas where WSSV is endemic avoid operating their farms during the coldest months of the year

In Madagascar and Mozambique pond water temperatures are coldest from mid-May to the end of September (figure 4.5). During this time period water temperatures are likely to average less than 27°C. These are the months when the risk of WSD outbreaks is highest. Shrimp farms can reduce their risk of WSD outbreaks by not operating the farm during this time period. That leaves 226 days between October 1 and May 15. Allowing 21 days between crops leaves only 205 growing days per year for two crops of shrimp.

Head-starting PLs in a Greenhouse

Some shrimp farms in Latin America have begun using indoor nursery systems (figure 4.6) to head-start their crops to regain the production days lost by avoiding the cold season. An indoor raceway system provides a biosecure production environment with warm water temperatures. Subsequent survival in the grow-out pond will generally be improved by stocking an advanced juvenile. *Litopenaeus vannamei* PLs are typically stocked at densities of up to 2,000–3,000 PLs/m^2 and grown to a size of 2.0–2.5 g in lined raceways. Optimal stocking densities for *P. monodon* nursery raceways would be lower, perhaps about 1,000 PLs/m^2 for a 50-day nursery period (Briggs 1991). Four 7m × 50m raceways stocked at 1,000/m^2 and harvested with 85

FIGURE 4.5: Annual Temperature and Salinity Variation for a Madagascar Shrimp Farm. Shaded Area Is the Time Period When Water Temperatures Are Less Than 27°C (After Corpron 2005)



percent survival would provide enough juveniles to stock one 10-ha pond at a density of 12/m^2.

Reduce Water Exchange

One of the most effective strategies for minimizing risk of WSD on farms is to operate the farm with little or no water exchange. Water exchange provides an opportunity for carrier organisms such as shrimp and crabs to enter the farm. Even filtered seawater may contain planktonic carriers such as copepods and crustacean larvae. In areas where there are active WSD outbreaks, free WSSV virions in the seawater will pass through even the finest screens and are capable of infecting shrimp in the ponds (Esparza-Leal et al. 2009). Reducing water exchange should be a part of every farm's strategy to reduce their risk of WSSV.

Water is exchanged in shrimp ponds to reduce the buildup of organic matter and nitrogenous wastes in the pond. Simply reducing water exchange rates is not a viable strategy since water quality will deteriorate and the carrying capacity of the pond will be reduced. However, there are many studies that show that water exchange can be reduced or eliminated in shrimp ponds by aerating the pond (Hopkins et al. 1993; Hopkins et al. 1995). Each kW of aeration can support an additional 500 kg of shrimp production (Boyd 1998). Shrimp ponds in Asia often have between 10 and 20 kW/ha of aeration, allowing them to produce 5–10 MT/Ha of shrimp with little or no water exchange.

Pond Aeration

In Asia aeration has been applied to intensify production in small ponds. Shrimp farmers in Madagascar and Mozambique have little interest in intensification of their culture systems. They have differentiated their shrimp in the marketplace by emphasizing the quality of their shrimp which they attribute to the outstanding environmental conditions in their low density ponds. The goal of aerating the ponds in this situation is not to intensify production, but to maintain current production levels with much lower rates of water exchange. In addition, aeration should help maintain higher dissolved oxygen levels to avoid stressing the shrimp. The addition of 5 kW/ha of aeration should allow stocking densities to be increased from 10 to 15 shrimp/m^2 without compromising product quality. The capital cost associated with adding 5 hp of aeration capacity to a farm is estimated at US$5,600/ha, including the cost of power generation and distribution (table 4.1). The additional production would pay for the cost of installing aerators and generators on the farm. Much of the additional operating cost associated with running paddlewheel aerators in the ponds is offset by the savings in reduced pumping costs.

Probiotics

Regular probiotic usage can improve the pond environment in several ways. Probiotics compete with pathogenic bacteria, such as *Vibrio harveyi* and *V. parahaemolyticus*, reducing the counts of the pathogenic bacteria in the water (Garriques and Arevalo 1995; Moriarty 1998). Several studies have demonstrated a

FIGURE 4.6: Indoor Nursery Raceway System for Head-Starting PLs (Photo: L. Drazba)

TABLE 4.1: Employment Cost of Adding 5 hp/ha of Paddlewheel Aeration for a 400-ha Shrimp Farm. The Cost Includes the Installation of Generators and Power Lines to Each Pond.

ITEM	UNITS	QTY	UNIT PRICE	TOTAL
Paddlewheel aerator, 2.5 hp	ea	800	$1,000	$800,000
Starter panel	ea	800	$200	$160,000
Power cabling	ha	400	$200	$80,000
Electrical distribution–power lines	ha	400	$2,000	$800,000
500 KVA generators–(2 KVA/KW)	ea	8	$50,000	$400,000
Total Cost	ha	400	$5,600.00	$2,240,000

relationship between the counts of bacteria that form green colonies on thiosulfate-citrate-bile-salts-sucrose (TCBS) agar plates (*V. harveyi*, *V. parahaemolyticus*, and *V. vulnificus*) and outbreaks of WSD (Gunalan et al. 2010; Tendencia and Verreth 2011). In addition probiotics are able to consume toxic nitrogenous wastes (Avnimelech 1999). Probiotics are a useful tool that can help maintain healthy conditions in a pond even under restricted water exchange. Regular probiotic usage will add about US$300/ha/cycle in operating costs.

Exclusion of Carriers by Filtration

Exclusion of carriers of WSSV should be a critical component of any farm level strategy for preventing WSD (Clifford 1999). There is no broad agreement in the industry with respect to the size of filter screen that should be used. To be effective, the water should be filtered down to at least 200 microns. From a biosecurity standpoint, WSSV risk decreases with screen size. That consideration must be balanced against the practicality of obtaining the required flow rates and frequency of cleaning.

Microscreen Drum Filters

Ideally all seawater entering the farm should be filtered before it is discharged into the water distribution canal. However, filtering the large volumes of water pumped onto the farms (6–20 m^3/sec) presents a challenge. A large amount of filtration surface area is required, and screens can become clogged very quickly. Microscreen drum filters provide a practical solution to these problems. Microscreen drum filters are mechanical, self-cleaning filters designed to filter fine suspended solids from the water at flow rates. A drum filter consists of a horizontally mounted cylindrical drum with fine-mesh screen wrapped around it. Water enters the front of the drum and passes through the screen. Suspended solids are deposited on the inner surface of the screen. The drum rotates slowly and solids are continually washed off the screen by a high pressure spray bar. Drum filters can be fitted with filter screens from 10–500 microns, and can handle flow rates of up to 500 L/sec with a 100-micron screen.

Filling a 400-ha shrimp farm in 30 days with 12 hours a day available for pumping requires a total pumping capacity of almost 7 m^3/sec. To filter this flow through 500 L/sec drum filters would require 14 units. The capital requirements for this filtration option are very high (table 4.2). Large drum filters can cost more than US$50,000 each.

TABLE 4.2: Estimated Cost for Installing a Microscreen Drum Filtration System with Filtration Capacity of 6 m^3/sec

DESCRIPTION	QUANTITY	UNIT PRICE	TOTAL COST
Microscreen drum filter–100 micron screen	12	$50,000	$600,000
Concrete weir and drum filter support structure	12	$40,000	$480,000
Electrical installation	12	$10,000	$120,000
Total estimated cost of microscreen drum filter and weir			$1,200,000

Including the cost of the concrete structures needed to mount and direct the flow through the drum filters, the final installed cost could reach US$100,000 per unit. While this option may be the ideal filtration option from a biosecurity standpoint, the cost will be prohibitive for most farms.

Bag Filtration of Seawater Entering a Pond

An affordable alternative to filtering the water before it enters the distribution canals is to filter it at the inlet gates for each pond. The traditional concrete inlet gate uses one or two flat 500-micron screens to exclude fish and crabs. Copepods and crustacean larvae easily pass through these screens. Using a finer 200-micron screen in the existing frames is not a good filtration option because the screens would require constant cleaning to keep them from clogging. In Latin America this problem has been overcome by using 4-m long filter bags. Typically the filter bags are set up with an inner and an outer bag. The inner bag has a course mesh (1 mm), while the outer bag is a finer mesh, usually 200 microns. The filter bags are attached to a frame that is mounted on the pond side of the inlet gate. The end of the filter bags are tied off. The length of the filter bag provides a large amount of surface area for filtration. The bags are self-cleaning in the sense that trapped solids are continually washed down to the end of the filter bag by the water flow, leaving most of the length of the filter clean for filtration. The accumulated solids need to be emptied from the end of the bag two or three times per day.

Materials for the filter bags cost about US$250 per inlet gate. Assuming one inlet gate for every 5 ha of pond area, the cost would be about US$50 per hectare of farm ponds.

Install Water Distribution Canal Drain Structures

Water distribution canals on many shrimp farms are rarely drained, and many even lack drainage structures. Over time they are colonized by a wide range of organisms, including fish, shrimp, crabs, oysters, and other crustaceans. The presence of a large biomass of potential carriers of WSSV represents a significant biosecurity risk for the shrimp farm. A simple and relatively inexpensive solution to this problem is to construct one or more drainage gates to facilitate regular draining of the distribution canal. After draining, the distribution canal should be dried out thoroughly before refilling to eliminate potential vectors living in burrows.

The estimated cost of constructing concrete water control structures for draining the distribution canal is about US$7,000 each.

Crab Fencing

Crabs can be an important reservoir host for WSSV (Lo et al. 1996; Kanchanaphum et al. 1998) and are abundant in the mudflats where most shrimp farms are built. The ability of crabs to travel over land means special measures are needed to exclude crabs from shrimp ponds. When properly maintained, crab fencing has proven to be an effective means of excluding crabs from shrimp ponds. Crab fences are plastic barriers typically about 50 cm high erected around the perimeter of a farm (figure 4.7).

Crab fencing is inexpensive, costing about US$500/km of fence. Crab fencing is only needed on farm perimeter levees and on levees between ponds and canals.

FIGURE 4.7: Crab Fencing

Photo: D. Jory

Bird Netting

Birds have long been suspected as vectors for transmission of WSSV. Following disease outbreaks, large numbers of seabirds are often attracted to the affected pond to feed on the dead and dying shrimp. It has been hypothesized that after feeding on infected shrimp, birds can transmit WSSV from one pond to another either by defecating or regurgitating. A study by Van Patten et al. (2004) demonstrated that while WSSV isolated from the feces of birds is noninfective, regurgitated WSSV remains infective. Many seabirds regularly regurgitate nondigestible food items.

In areas where WSSV is endemic, many shrimp farms now cover the ponds with bird netting or monofilament scare lines to exclude birds from shrimp ponds. Data from a farm in Malaysia shows that bird netting can effectively prevent the spread of WSSV from infected ponds to other ponds on the farm. Even very large ponds can be covered with monofilament netting supported on cables strung between support posts anchored in the pond bottom (figure 4.8). The cost for covering a shrimp pond with monofilament netting is approximately US$2,000/ha.

Disinfection of Seawater Entering the Farm

Filtration systems are effective at preventing vectors larger than the mesh size of the screen, but it is still possible for WSSV to enter a pond either as free virions or in planktonic carriers such as copepods. Disinfection of the pond water with chlorine or ozone can be an effective way of inactivating WSSV that passes through the mechanical filtration systems. WSSV has been shown to be inactivated by exposure to 200 ppm of sodium hypochlorite for 10 minutes (Balasubramanian et al. 2006). In pond applications the OIE (2013) recommends maintaining a minimum free chlorine level of 10 ppm for 24–48 hours after filling. Free chlorine should be monitored at regular intervals and calcium hypochlorite should be reapplied as necessary to maintain this minimum concentration. An initial application rate of 30 ppm of free chlorine will usually be sufficient to maintain the required 10 ppm of chlorine for 24 hours. After treatment the pond should be allowed to sit for 4 or 5 days before stocking to allow the chlorine to dissipate.

A total of 462 kg of granular chlorine (65 percent chlorine) is required to treat 1 ha of pond area filled to a depth of 1 m. Assuming a cost of US$1.20/kg for granular chlorine, the cost for disinfecting

FIGURE 4.8: Bird Netting

Photo: P. Van Wyk

Photo: G. Chamberlain

a pond prior to stocking is US$554/ha. For a farm producing 2,000 kg/ha per crop, disinfecting the pond prior to stocking would add US$0.28/kg to the production cost.

Chlorinating the water within the shrimp pond disinfects the initial fill of the pond, but a separate treatment reservoir is required to chlorinate water used for water exchanges. If the total time required to treat the water is 4 days, two treatment ponds will be needed to ensure a continuous supply of disinfected seawater. Each of the ponds should have a volume of four times the daily farm water requirement. If the farm is exchanging 5 percent of the pond volume per day, the total volume of the treatment ponds would equal 40 percent of the volume of the production ponds. This is not a cost-effective use of pond area.

4.7 HATCHERY-LEVEL STRATEGIES FOR CONTROLLING WSSV

Stocking postlarvae produced from wild broodstock is the single biggest risk factor for the development of WSD in shrimp farms. Infected broodstock transmit WSSV to their offspring. Once WSSV becomes established in wild populations, the use of wild broodstock in the hatchery is likely to result in outbreaks of WSD on the farm.

PCR Testing of Wild Broodstock

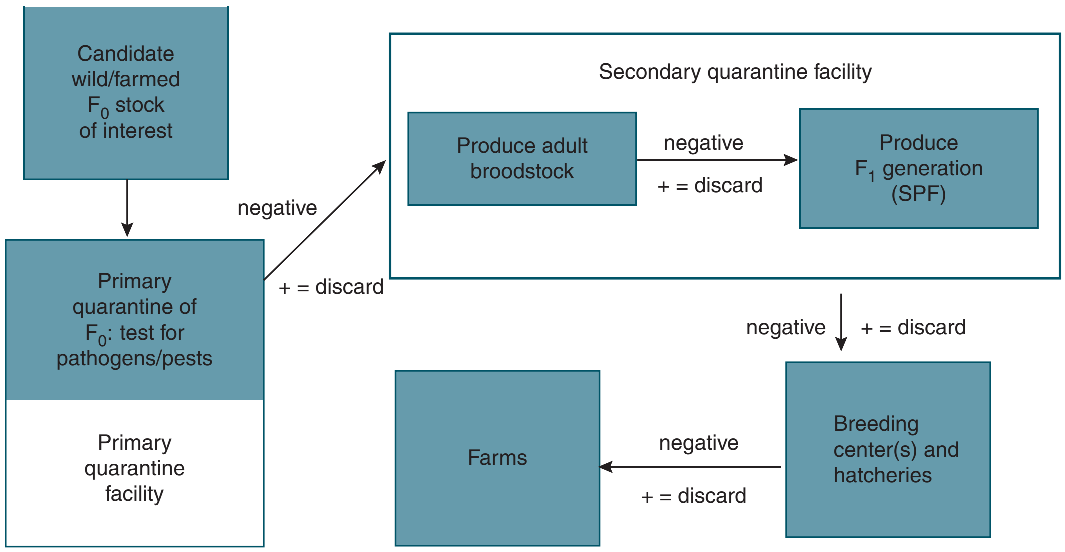
If domesticated broodstock are not available, the risk of vertical transmission of WSSV can be mitigated by quarantining and PCR testing of broodstock for WSSV and other OIE-listed viruses. For this to be effective the broodstock must be quarantined in individual holding tanks and each shrimp must be individually tested. Any shrimp testing positive should be destroyed. However, a negative PCR test does not guarantee that the shrimp is not infected with WSSV. The viral load in shrimp with latent infections may be below the detection limit, especially if PCR samples are pooled. The stress of spawning may weaken the host immune system allowing the virus to replicate. Shrimp that test negative for WSSV may test positive after spawning (Hsu et al. 1999). If wild broodstock are used, it is essential that the female breeders be retested for WSSV after each spawn. A sample of PLs should also be stressed and PCR-tested and only PLs with negative test results should be stocked on the farms.

SPF Broodstock

The use of screened wild broodstock should be seen only as an interim strategy for obtaining disease free seedstock. The long-term strategy for ensuring the disease free status of seedstock is to replace wild broodstock with SPF broodstock. The replacement of wild broodstock with SPF broodstock has been a key factor in the recoveries of both the Asian and Latin American shrimp industries from WSSV. In a 2006 report on the state of world aquaculture, the Food and Agriculture Organization concluded that without the importation and use of SPF broodstock, it is unlikely that Asia's major shrimp producing countries could have recovered from outbreaks of WSSV and other viral diseases, given the severe shortage of healthy wild-caught broodstock (FAO 2006).

The term SPF has often been misused and misunderstood. By definition, SPF only refers to shrimp that are free of specific pathogens.

FIGURE 4.9: Steps to SPF Stock Development as Developed by the U.S. Marine Shrimp Farming Program (After Lightner 2011)



SPF status is not a heritable trait nor is it a lifetime condition. SPF shrimp can become infected when exposed to a pathogen. SPF shrimp have neither innate resistance nor innate susceptibility to a particular pathogen. The advantage of using SPF seedstock is that they are free from disease at the time they are stocked. If the pathogen can then be excluded from the culture environment, disease caused by that pathogen can be avoided.

The development of SPF broodstock is an involved and time-consuming process (Lotz 1992; Moss et al. 2003; Lightner 2011). This involves collecting shrimp from the wild and transferring them to a primary quarantine facility (figure 4.9) where they are analyzed for specifically listed pathogens. If they test negative, they are transferred to a secondary quarantine facility where they are spawned to produce an F1 generation of captive shrimp. If shrimp from the F1 generation test negative for specifically listed pathogens after several successive screenings, they are transferred to a nucleus breeding center where they become part of the SPF breeding population. The process of developing SPF broodstock requires at least 2 years.

There are two companies in the region (Unima and Oso Farming LGA) that have already developed SPF *P. monodon* broodstock. It would be a tremendous advantage for the region if a means can be found to make SPF breeders or seedstock from these two companies available to the other producers in the region.

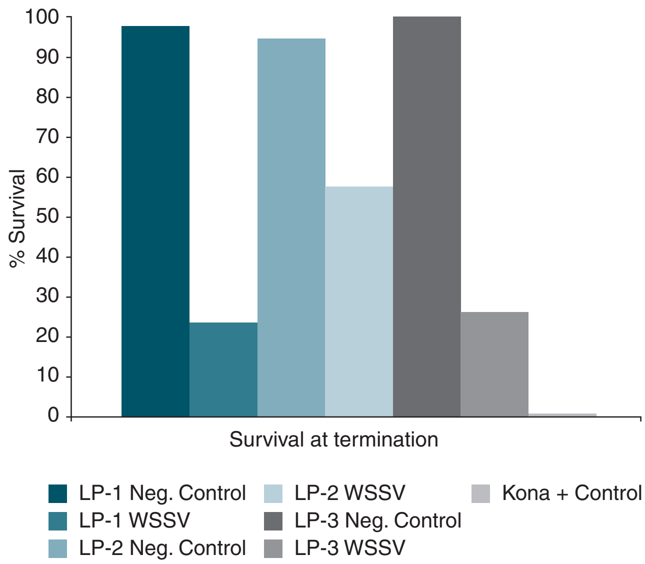
WSSV-Resistant Broodstock

Once a sufficient number of genetically distinct families are developed for the SPF breeding program, it is not necessary to continue collection of new families from the wild. At that point, the SPF development program transforms into a domestication program. Careful attention will need to be paid to the families that are being created to prevent inbreeding. Ideally a few important traits will be selected for to improve the performance characteristics of the shrimp. The three most important characteristics of any culture species are its growth rate, its breeding fecundity, and its survival in the culture system. In an environment where viral disease is a constant threat, breeding for disease resistance can substantially improve survivability in the culture system.

For example, a selective breeding program initiated by a Panamanian shrimp company in 2001 has resulted in the development of significant resistance to WSSV in three selected lines of *L. vannamei* (Cuéllar-Anjel et al. 2012). In trials where shrimp from different genetic lines were challenged per os with WSSV, survival was 23 percent, 26 percent, and 57 percent 17 days after exposure in shrimp from families selected for WSSV-resistance, compared to 0 percent in unselected controls (figure 4.10).

In Latin America development of WSSV-resistant stocks has been an important part of the strategy for industry survival now that WSSV is endemic in the environment. However, the benefits of

FIGURE 4.10: Survival by Family in a WSSV Challenge Study of Genetic Lines Selected for Resistance to WSSV by a Panamanian Shrimp Company (After Cuéllar-Anjel et al. 2012)



selective breeding for disease resistance generally require several years of effort. The resistance to WSSV presented in the Panamanian example is the result of 10 years of selection for WSSV resistance.

Selective breeding programs are expensive. Annual costs to operate a small breeding center would likely be between US$500,000 and US$1,000,000 per year. This makes operation of a selective breeding center too expensive except for large shrimp companies. However the cost of PLs produced from the selected broodstock declines as the number of PLs produced increases (table 4.3). For a program that costs US$1,000,000/year to operate, the breeding cost per thousand PLs drops from US$10/1,000 PLs to US$4/1,000 PLs as PL production increases from 100 million to 250 million PLs per year. The estimated annual demand for PLs for the entire Mozambique Channel shrimp industry is approximately 600 million PLs per year. This demand could easily be met by one breeding center. Sharing the cost of a single regional breeding center would be a cost-effective option for the farms in the region.

Affordability of Biosecurity Improvements

A financial analysis was conducted to determine the affordability of investing in biosecurity upgrades to the farm facilities. In our interviews with representatives of the different farms, the team gathered information on typical production parameters such as stocking

TABLE 4.3: Breeding Center Cost Per 1,000 PLs as a Function of the Number of PLs Produced Per Year from the Breeders and the Breeding Center Annual Budget

NO. OF PLS PRODUCED/YR FROM BREEDERS	BREEDING CENTER $500,000	ANNUAL BUDGET $1,000,000
50 million	$10.00	$20.00
100 million	$5.00	$10.00
200 million	$2.50	$5.00
300 million	$1.67	$3.33

densities, survivals, length of crop cycles, number of crop cycles per year, average weight of shrimp harvested, water exchange rates, and food conversion ratios. We also gathered information on prices received for the shrimp and costs of labor, management, feed, diesel consumption, and processing costs. Finally, we gathered information on investment costs and costs for various upgrades such as bird netting, paddlewheel aeration, generators, microscreen drum filters, and so on.

Using the information gathered, an enterprise budget was developed for a "typical" 400-ha Mozambique Channel shrimp farm. This model assumed no investment in biosecurity improvements. We

TABLE 4.4: Salient Features of Three Different Biosecurity Improvement Strategies Compared with a Typical Farm with No Biosecurity Improvement Strategy

Stock SPF PLs from breeding center		X	X	X
Drainage gates on SW distibution canal		X	X	X
Bird netting over ponds		X	X	X
Crab fencing		X	X	X
Regular probiotic treatments of ponds		X	X	X
Aeration–5 hp/ha			X	X
Water exchange rate	15%/day	10%/day	0%/day	0%/day
Stocking density	9/m^2	6/m^2	13.5/m^2	13.5/m^2
Increased capacity of processing facilities			X	X
200-micron bag filters on inlet gates		X	X	
100-micron microscreen drum filters				X

then calculated the investment requirements for implementing different biosecurity upgrades (table 4.4). To simplify the analysis we examined the financial consequences associated with three biosecurity strategies or scenarios.

Stocking SPF PLs was a common element to all three strategies. We assumed this increased the cost of PLs from US$10.00/thousand to US$14.00/thousand. Other improvements common to all plans included crab fencing, bird netting, probiotic usage, and drain structures to allow drainage of seawater distribution canals. The main distinguishing feature between Biosecurity Strategy #1 and the other two strategies is aeration. Strategy #1 assumes no aeration is added to the ponds while Biosecurity Strategies #2 and #3 both include the addition of 5 hp/ha of aeration. Water exchange without aeration can only be reduced by lowering stocking densities. The addition of 5 hp of aeration per hectare should allow water exchange to be nearly eliminated. With 5 hp of aeration per hectare it should be possible to produce approximately 2,500 kg/ha without water exchange (Boyd 1998). The addition of aeration allows stocking rates to be increased from 9/m2 to 13.5/m^2. Production under this scenario would be 2,363 kg/ha, assuming 70 percent survival and a harvest weight of 25 g. Biosecurity Strategies #2 and #3 differ from one another in the technology selected for seawater filtration. Biosecurity Strategy #2 utilizes 200-micron bag filters attached to the inlet structures while Biosecurity Strategy #3 uses microscreen drum filters.

The costs and returns for each of the four scenarios are presented in table 4.5. These are the key conclusions drawn from this analysis:

- Reducing stocking densities to allow for lower water exchange rates is not a viable biosecurity strategy. The gains in biosecurity are minimal and the reduced productivity of the farm may very well make the farm unprofitable.
- The addition of 5 hp/ha of aeration should allow for a significant increase in productivity from 1.57 MT/ha/crop to 2.36 MT/ha/crop, while minimizing the need for water exchange.
- Biosecurity Strategy #2 (aeration plus bag filtration) increases productivity, reduces overall operating costs, and improves the profit margin. Net returns per kg of shrimp produced are estimated at US$1.25/kg with no biosecurity plan and US$2.00/kg under Strategy #2.
- The most biosecure strategy, in which aeration and microscreen drum filtration is used, is very capital intensive with an expected investment cost of about US$14 million dollars for a 400-ha farm. Despite the high cost, the profit per kg of shrimp is reduced by only US$0.12/kg.

4.8 STATUS OF FARM-LEVEL IMPLEMENTATION OF BIOSECURITY PLANS

Mozambique

At Aquapesca, there have been marginal improvements in biosecurity. The main change in production strategy is the entire farm is now dried out for 2 1/2 months between cycles, and ponds are not stocked during the winter months. In the summer, the ponds do not dry out completely, so puddles are now chlorinated. Water exchange rates have been reduced and no water is exchanged during the first 30 days of the production cycle. Incoming water is still filtered through a 500-micron screen. There are no plans to install aeration to allow further reductions in water exchange rates. Aquapesca produces shrimp with organic certification. The organic certification program allows only emergency aeration.

At the Nacala hatchery Aquapesca has implemented a quarantine and PCR testing program so that 100 percent of the broodstock brought to the facility are screened with PCR testing (figure 4.11). Water treatment at the hatchery now includes chlorination of all water entering the hatchery. Every lot of PLs is now PCR-tested following a stress test before shipment to the farm.

FIGURE 4.11: Broodstock Quarantine System at the Aquapesca Nacala hatchery (Photo: PP Blanc)

TABLE 4.5: Investment Analysis of Three Different Strategies for Improving Farm Biosecurity

ITEM	NO BIOSECURITY STRATEGY	BIOSECURITY STRATEGY #1	BIOSECURITY STRATEGY #2	BIOSECURITY STRATEGY #3
Total farm investment before biosecurity upgrades	$12,000,000	$12,000,000	$12,000,000	$12,000,000
Processing plant investment before upgrades	$8,000,000	$8,000,000	$8,000,000	$8,000,000
Investment biosecurity upgrades	$0	$864,800	$6,104,800	$14,060,000
Total capital investments	$20,000,000	$20,864,800	$26,104,800	$34,060,000
Production Assumptions				
Total farm production pond area	400 ha	400 ha	400 ha	400 ha
Stocking rate	9.0 PLs/m^2	6.0 PLs/m^2	13.5 PLs/m^2	13.5 PLs/m^2
Survival rate	70%	70%	70%	70%
Shrimp harvest weight	25 g	25 g	25 g	25 g
Average yield per ha per cycle	1,575 kg/ha	1,050 kg/ha	2,363 kg/ha	2,363 kg/ha
Growing days per production cycle	110 days	110 days	110 days	110 days
Feed conversion rate (FOR)	1.80	1.80	1.80	1.80
Number of production crops per year	2 crops/yr	2 crops/yr	2 crops/yr	2 crops/yr
Annual production per year	1,260,000 kg	840,000 kg	1,890,000 kg	1,890,000 kg
Revenues	**$/kg**	**$/kg**	**$/kg**	**$/kg**
Annual revenues from shrimp sales	$11.00	$11.00	$11.00	$11.00
Variable Costs	**$/kg**	**$/kg**	**$/kg**	**$/kg**
Shrimp postlarvae	$0.57	$0.80	$0.80	$0.80
Feed (kg)	$2.52	$2.52	$2.52	$2.52
Fertilizer and lime	$0.16	$0.24	$0.11	$0.11
Probiotics	$0.00	$0.14	$0.06	$0.06
Supplies	$0.16	$0.24	$0.11	$0.11
Diesel fuel for pumping	$0.38	$0.39	$0.09	$0.09
Diesel fuel for aeration	$0.00	$0.00	$0.70	$0.70
Wages and benefits	$1.00	$1.50	$0.66	$0.66
Processing cost	$1.75	$1.75	$1.75	$1.75
Repair and maintenance	$0.40	$0.60	$0.26	$0.26
General and administration	$1.15	$1.73	$0.77	$0.77
Total variable cost/kg	$8.09	$9.90	$7.83	$7.83
Fixed Costs	**$/kg**	**$/kg**	**$/kg**	**$/kg**
Depreciation on farm investment (15 yr straight line)	$0.63	$0.95	$0.42	$0.42
Depreciation of processing plant investment	$0.63	$0.95	$0.08	$0.42
Interest on original capital investment	$0.40	$0.60	$0.26	$0.26
Depreciation on biosecurity capital improvements	$0.00	$0.10	$0.32	$0.74
Interest on biosecurity capital improvements	$0.00	$0.03	$0.08	$0.19
Total fixed costs	$1.67	$2.63	$1.17	$2.04
TOTAL COST	$9.75	$12.53	$9.00	$9.87
Net returns above variable and fixed costs	$1.25	−$1.53	$2.00	$1.13
Simple return (Net returns ÷ Total investment × 100%)	7.9%	−6.2%	12.0%	6.3%

Aquapesca understands that the long-term solution PL biosecurity is to develop an SPF breeding facility. François Grosse, director of Aquapesca, expressed his desire for the development of a national SPF breeding facility funded by the World Bank. The breeding facility would be operated as a business, but 10 percent of the PLs would be made available to small-scale Mozambican shrimp farmers free of charge. This would satisfy the government's goal of supporting the development of small-scale aquaculture.

At the time of our visit in May 2013, Sol y Mar was not operating. They are considering several modifications of the farm to improve biosecurity, including the installation of 5 aerators per pond to allow the ponds to be operated with minimal water exchange, and the installation of a 70-m deep seawater well for each of the 58 grow-out ponds. They are also planning to clean and recontour the dikes for the ponds which will allow them to do a better job of controlling crabs in the ponds. The dikes are also in need of maintenance from erosion over the years. The total budget for the renovations is US$2.66 million dollars. Sol y Mar believes that by moving to a biosecure, zero or low exchange production system with 10 hp/ha of aeration they can increase their production to 5 MT per hectare per year. The additional revenue generated at this level of production would justify the cost of the renovations.

Madagascar

The Unima Group has a comprehensive biosecurity plan to protect their farm from WSD. The main elements of the plan are as follows:

- Early detection through surveillance of WSSV infections in wild carrier populations along the Madagascan coast and near the farm.
- A contingency plan when WSSV is detected near the farm that calls for stopping of all pumping and immediate emergency harvest of shrimp larger than 15 g.
- Installation of 1 mm prefilters, settling ponds, and 35-micron microscreen drum filters to remove most WSSV carriers before they enter the water supply canal.
- Installation of an ozone water treatment system to kill waterborne WSSV and planktonic carriers.
- Construct a drainable concrete-lined canal system on top of the pond levees.
- Reducing the water exchange requirements by adding additional aerators to the ponds, bringing the total aeration to 10 hp/ha.
- Dividing the 10-ha ponds in half lengthwise to improve water circulation patterns.
- Improving water quality in the ponds through extensive use of probiotics.

The Unima Group hatcheries already produce SPF postlarvae and have been engaged in selective breeding since 2003 (Le Groumellec et al. 2011). Unima believes these capital improvements will allow them to improve production capacity from 2 MT/crop to 3.5–4.0 MT/crop. The increase in production capacity will require increases in the hatchery production capacity and processing capacity. Unima estimates the proposed upgrades will cost nearly US$30 million dollars for the two farms.

The Oso Farming biosecurity plan is a management-based plan. The key elements of the plan include:

- Early detection of WSSV by mounting massive surveillance of WSSV in wild populations on the northwest coast of Madagascar.
- Emergency harvesting and processing of marketable shrimp if WSSV detected near the farm.
- Strict enforcement of biosecurity policies on the farm with respect to personnel.
- Stocking SPF postlarvae from the LGA hatchery.
- Breeding program to develop WSSV-resistant breeding lines.
- Avoid stocking during the winter months.
- Avoid stressing shrimp by strict management of pH, temperature, salinity, and redox potential ("Oso Cube of Comfort").

This biosecurity plan is unconventional and risky in that it does not rely on exclusion of carriers through reduced water exchange, microscreen filtration, crab fences, bird netting, or disinfection of water supplies. The management believes that stocking SPF WSSV-resistant PLs and maintaining an optimal culture environment will prevent the manifestation of WSD. They also believe they are only months away from having a breeding line with significant resistance to WSSV.

The Aquamas biosecurity plan includes the following elements:

- Quarantine and screen broodstock for WSSV before moving them into the maturation section of their hatchery.
- PCR testing of postlarvae before stocking.
- Conversion of a 50 m × 800 m section of the main water supply reservoir into a chlorination reservoir. Seawater will be disinfected with 30 ppm of chlorine; the seawater will

remain in the chlorination reservoir for 4 days to allow the chlorine to dissipate.

- Filtration of water through 250 micron screens mounted on concrete gates at the entrance to lateral branches of the water supply canals.
- Avoid stocking during the cold season.

A section of the farm has been modified and production trials are currently underway to test the system.

In May 2013, ASH told Aquamen they would be permitted to resume operations if they agreed to a biosecurity plan similar to the Unima's plan (D. Chauty, personal communication). The company does not have the financial resources to follow this plan. In the meantime, Aquamen remains closed.

4.9 NATIONAL RESPONSES TO THE MOZAMBIQUE CHANNEL WSSV CRISIS

Control Options

Based on the lessons from Asia and Latin America, there are three broad control options that governments have for dealing with an outbreak of white spot disease (DAFF, 2005):

1. Eradication
2. Zoning and Containment
3. Control and Mitigation

The appropriate response is a function of the how widely distributed the infection is in the wild population. Eradication is possible only in the earliest stages of introduction of WSSV to a new area, when the virus is not yet established in the wild population. Eradication requires immediate destruction and disposal of all stocks in facilities where the disease has been detected, disinfection and retention of water at the infected facility, and creation of a quarantine buffer zone around the facility. Widespread surveillance is required to demonstrate that WSSV has not spread beyond the infected facility. The eradication option was not applicable in the case of Mozambique and Madagascar, because the disease appeared to originate from infected wild shrimp detected in multiple locations in the Mozambique Channel and possibly originating from Saudi Arabia.

If the pathogen has a localized distribution in the wild, then the objective of the management program is containment of the pathogen so that it does not spread. Policies to contain the spread of WSSV may include:

1. PCR testing of broodstock and postlarvae
2. Pond level monitoring for WSSV and destruction of shrimp in infected ponds
3. Restrictions on discharge of water from infected facilities without prior disinfection
4. Zoning to define disease-free and infected zones
5. Quarantine and restrictions on the movement of shrimp out of the infected zone
6. Regional surveillance monitoring of wild populations to determine distribution and movements of the virus and to provide early warning to farms in disease-free zones

Once WSSV becomes endemic to a region and broadly distributed in wild populations, the strategy then shifts from containment to mitigation. Governments can assist by conducting routine disease surveillance, training in disease management procedures, financial assistance to farms implementing biosecurity enhancements, and support to cooperative efforts to produce SPF and disease-resistant seedstock. Individual farms must take responsibility for implementing management strategies and biosecurity procedures to minimize the impact of WSSV.

Response of the Mozambique Government

After receiving notification from the CB-UEM and UAZ laboratories that the Aquapesca disease outbreak was caused by WSSV, a high- level meeting was called on September 15, 2011 that included representatives from APCM, INAQUA, INIP and the National Fisheries Research Institute (IIP). The objectives of this meeting were to inform the Competent Authority (INIP) of the situation and to formulate a plan on how to respond to the outbreak. A technical committee was formed with members from each of the organizations represented at the meeting. The committee was tasked with planning and coordinating the response to the WSSV outbreak. The response to WSSV included legislation, development of a WSSV surveillance program, setting up a national diagnostic laboratory for aquatic animal diseases, and training for INIP personnel in diagnosis of diseases of aquatic organisms.

The first official response to the outbreak of WSD in Mozambique was the issuing of a decree banning the transport of live and frozen crustaceans between provinces. The goal of this ban was to prevent the spread of WSSV from the zone of active infection to noninfected areas. The Ministry of Fisheries based this policy on the recommendations contained in the Australian Aquatic Veterinary Emergency Plan (AQUAVETPLAN) developed for controlling WSD by the Australian Department of Agriculture, Fisheries and Forestry (DAFF 2005). AQUAVETPLAN recommends that as soon as WSD is diagnosed in a new region the following zones should be set up and enforced:

- Restricted areas—areas around infected premises or areas
- Control areas—buffer zones between the restricted areas and free areas
- Free areas—areas that are free from infection or are of unknown status

All movements of potential vectors for WSSV, especially live and frozen crustaceans, should be contained within the restricted and control areas.

The effectiveness of this strategy depends on the degree to which the disease is established in wild populations and the geographic distribution of the infected population. This strategy can be very successful when a WSD outbreak results from a recent, point source introduction such as happens when WSSV is imported with purchased broodstock or PLs. The strategy of preventing the spread of disease through restriction of commercial transport of potential carriers is less likely to be effective if reservoirs of WSSV have already become established in wild host populations. The fact that shrimp can be infected with levels of WSSV below the detection limit for PCR testing may allow WSSV to spread and become established in reservoir populations. In Mozambique surveillance testing conducted in late 2011 revealed that WSSV was widely distributed along the Mozambican coast. However, the distribution of WSSV in the wild was unknown at the time the Ministry of Fisheries banned the transport of crustaceans between provinces.

At the time of WSSV outbreak there was no legislation in Mozambique establishing policies on aquatic animal health. The WSSV technical committee recognized the need for a policy framework for aquatic animal health and began work on two legislative documents related to aquatic animal health:

- **Aquatic Animal Health Plan** (Omar 2011), also known by its Portuguese acronym PESAAQUA (Plano de Sanidade dos Animais Aquaticos), is closely modeled on the Australian AQUAVETPLAN disease strategy for controlling white spot disease (DAFF 2005). PESAAQUA outlines disease control principles to be followed by the Competent Authority in the case of an outbreak of WSD. Included in the emergency plan are chapters discussing various response strategies to WSD outbreaks: confirmation of infection, destruction and disposal procedures, decontamination procedure, containment and control strategies, and principles for setting up a surveillance plan. PESAAQUA was submitted to the Ministry of Fisheries for approval in July 2013.
- **Health Regulations for Farmed Aquatic Animals** will specify the aquatic animal health regulations that each aquaculture operation must adhere to and will be based on the OIE Aquatic Animal Health Code (OIE 2011). This document was presented to the Ministry of Fisheries on May 18, 2013. The ministry decided that the aquatic animal health regulations should be included as part of the existing terrestrial animal health laws and that the Competent Authority should be under the Veterinary Services. While this makes sense from an organizational standpoint, the change will further delay the development of a functional aquatic animal health authority in the country due to the lack of trained personnel, organizational structures and laboratory facilities with the Veterinary Services.

The WSSV technical committee also recognized the need to determine the prevalence of WSSV in wild populations of crustaceans along the entire Mozambican coast. The APCM technical assistant, with input from INAQUA and INIP, designed and implemented an epidemiological surveillance program. There was no money in the Ministry of Fisheries budget for such a program, so the AFD funded it in 2011 using funds diverted from an aquaculture sector capacity building project. Wild shrimp and crabs were sampled in all coastal provinces and sent to a private lab in Ecuador for PCR analyses. When the results of the first 500 samples were reported by testing laboratory in December, it became clear that WSSV was well established in

most areas along the Mozambican coast, with prevalence reaching as high as 32 percent on the coast of Nampula province. The Nacala hatchery is in Nampula. The surveillance program continued in 2012 with funding from the Ministry of Fisheries.

At the request of the Mozambique government, the OIE scheduled a Performance of Veterinary Services (PVS) mission to Mozambique from November 10–16, 2011. The OIE PVS missions are designed to assist the veterinary services of OIE member countries to establish their current level of performance and to identify gaps and weaknesses in their ability to comply with OIE international standards (OIE 2013). The PVS was scheduled prior to the outbreak of WSSV in the country. The objectives of the mission were expanded to include evaluation of the ongoing WSSV crisis in Mozambique: origins of disease, actions of private sector stakeholders, actions of public sector stakeholders, and public-private stakeholder cooperation. The OIE PVS mission report (Le Groumellec 2011) provides a detailed account of the events associated with WSSV outbreak, as well as offering excellent recommendations for strengthening Mozambique's ability to manage aquatic animal health issues. The OIE examiner, Dr. Marc Le Groumellec, is a veterinarian specializing in shrimp pathology employed by the Unima Group in Madagascar.

4.10 RESPONSE OF THE MADAGASCAR GOVERNMENT

Following the official declaration of infection on May 9, ASH issued a decree banning the importation of crustacean species that might infect Madagascar shrimp. This was done to prevent shrimp that were caught elsewhere from being brought to Madagascar for processing. It was also intended to prevent WSSV-infected processed shrimp from entering the country.

The Competent Authority at ASH inspected the Aquamen facility, accompanied by Dr. Marc Le Groumellec, acting in the capacity of OIE examiner. On the recommendation of Dr. Le Groumellec, the Competent Authority ordered a program of stamping out the WSSV infection at the farm. The specific measures Aquamen was ordered to take to eradicate the virus included:

- All shrimp stocks should be slaughtered, removed from the ponds, and buried with quicklime (CaO).
- Discontinue all pumping activities and block off all drain gates to avoid releasing any contaminated water into the environment. The collection of the slaughtered shrimp from the ponds must be accomplished without discharging water from the farm.
- Destroy all broodstock and larvae. Shut down and disinfect the hatchery.

ASH has not allowed Aquamen to resume operations pending submission and approval of a biosecurity plan.

Except for the actions listed above, the Competent Authority in Madagascar has been willing but unable to respond to the WSSV crisis. The executive director of ASH cited the following reasons for their limited response to the crisis:

1. Insufficient financial resources to establish a functional emergency plan.
2. Lack of financial resources to assist farmers' efforts to fight the disease.
3. Difficulties in finding and hiring scientists specialized in shrimp diseases.
4. Lack of communication between private sectors carrying out surveillance programs and ASH makes it difficult for ASH to respond to new cases.
5. Delays in reporting of diagnostic results do not allow for rapid response to new cases.
6. The remote location of farms and the difficulties in communication hamper regulatory efforts.

Although ASH is the legal authority and is empowered to take the necessary steps to limit the disease outbreak, it is paralyzed by lack of financial resources. It is hesitant to impose regulatory constraints, because ASH recognizes that the private farms are often better funded and have better access to international experts to assist in managing the crisis.

A Private Sector Surveillance Program was established in July 2012 following a proposal submitted by GAPCM for a joint effort of the LES and the private PCR labs operated by the Unima Group and Oso Farming LGA. Despite recognition by all stakeholders of the critical importance of such a program, the Ministry of Fisheries had no funds available to support surveillance activities. The private sector has had to shoulder both the workload and the cost of

WSSV surveillance sampling and testing. Since September 2012, Unima has collected 4,442 samples, processed 2,234 samples, and found 59 samples positive for WSSV (2.6 percent). Since March 2013, the only positive samples have been collected from near Soalala. Since May 2012, the LGA has conducted more than 37,000 PCR tests on samples collected for their own surveillance program. Unfortunately, there is little communication between these two companies, resulting in potential duplication of effort. At the concluding workshop of this mission on May 21–22, Unima and LGA agreed to share their PCR results with the other shrimp farms in the country and with ASH.

4.11 SUBREGIONAL SHRIMP AQUACULTURE BIOSECURITY PLAN FOR THE MOZAMBIQUE CHANNEL

In April and May 2013, FAO with financial support from the World Bank and AFD, convened regional workshops hosted by the Instituto Nacional de Desenvolvimento da Aquacultura and the Autorité Sanitaire Halieutique in Maputo and Antananarivo, respectively. The principle objective for the workshops was to develop a framework for a subregional program to improve aquatic animal health capacity in the countries of the Mozambique Channel (for example, EU 2006). The following principles served as guidance in the preparation of this program (FAO 2007).

- Countries require a minimum level of national and regional aquatic animal health capacity in order to protect their living aquatic resources (including aquaculture), natural aquatic environments, and aquatic biodiversity from the negative impacts of pathogens and disease.
- Increased aquatic animal health capacity should enable aquaculture to make a greater contribution to the economies of these countries through healthy aquatic production, increased competitiveness in international markets, and improved economic viability at the national level.
- Countries share a common marine environment and thus serious aquatic animal pathogens introduced to the waters of one country have the potential to spread and negatively affect aquaculture and/or the wild fisheries of another country. Thus, countries have a shared responsibility to prevent the introduction of exotic pathogens and to implement sound and sustainable aquaculture practices.
- Movement of living aquatic animals within and across national boundaries is important for economic, social, development, and public resource purposes. The benefits of such movements must be weighed against the potential risks, and authorities should implement informed decisions.
- National and regional aquatic animal health strategies, plans and programs should be consistent with obligations to the World Organization for Animal Health and/or the World Trade Organization (WTO) and other relevant treaties and agreements.
- Countries are encouraged to develop and formalize national aquatic animal health strategies and health management procedures that adhere to international and regional standards and be harmonized on as wide a basis as possible.
- Countries should encourage industries to use preventative measures to limit their exposure to pathogens and disease. Such measures include but are not limited to the use of better management practices (BMPs), health certification, specific pathogen-free and high health (HH) stocks, quarantine, and vaccination protocols, as applicable.

Recognizing that the countries share a common marine environment and that serious aquatic animal pathogens introduced to the waters of one country have the potential to spread and negatively affect aquaculture and/or the wild fisheries of another country, sovereign governments have a shared responsibility to prevent the introduction of exotic pathogens and to implement sound and sustainable aquaculture practices. The key objectives of a comprehensive aquatic animal health program should be:

1. To develop a governance system that promotes biosecurity, national strategies for aquatic animal health should be developed and national legislation regarding aquatic animal health should be reviewed to make sure it is consistent with international standards.
2. To promote subregional preparedness for AAH crises, individual countries should develop emergency operational response plans and train personnel in their implementation.
3. To improve disease diagnostics regional reference laboratories for diagnostic testing should be recognized; reference laboratories should participate in proficiency testing; costs should be standardized.
4. To improve disease surveillance, regional surveillance programs should be designed and personnel trained to implement the surveillance programs; surveillance data

should be used to contain pathogens in infected areas and protect noninfected areas.

5. To minimize risk from new or exotic pathogens, minimum biosecurity standards and best management practices should be agreed upon and farms should be required to meet those standards and trained in best management practices.
6. To promote sustainable aquaculture development and responsible investment in shrimp aquaculture each country must create an enabling environment by providing AAH services, disseminating information on regional aquaculture practices, facilitate the formation of farmer associations, and develop mechanisms for risk management.
7. To promote the strengthening of national aquaculture institutions, governments should support students seeking degrees in AAH, and should invest in strengthening national diagnostic and research infrastructure.
8. To promote regional collaboration, networking and sharing of information and resources, a web portal for AAH should be developed in which surveillance data and other AAH information is shared; there should also be regional collaboration and sharing of resources such as genetic resources, and feed.
9. Regular and special or emergency meetings should be held between regional stakeholders to promote regional cooperation and collaboration.

The preparation of the subregional program for the Mozambique Channel involved two main activities: (1) an aquatic animal health performance and capacity assessment in the three countries using an FAO survey questionnaire; and (2) a 3-day subregional meeting of representatives from each of the three countries to discuss the results of the survey and develop the strategy.

The FAO survey questionnaire contains 18 sections pertaining to: (1) international trade in live aquatic animals and national border controls; (2) control of domestic movement of live aquatic animals and other domestic activities that may spread pathogens; (3) policy and planning; (4) legislation; (5) disease surveillance/monitoring; (6) disease diagnostics; (7) emergency preparedness and contingency planning; (8) extension services; (9) compliance/enforcement; (10) research; (11) training; (12) expertise; (13) infrastructure; (14) linkages and cooperation; (15) funding support; (16) current challenges; (17) constraints; and (18) additional information. The survey was conducted from February to March 2013. Based on the survey results, a SWOT analysis exercise (box 4.1) was conducted during the workshop.

The program elaborated at the workshop consists of eight components within which are 12 elements containing a total of 42 activities. Each component is accomplished by completing the indicated activities. These include actions to be taken by individual countries in support of their national aquatic animal health strategies, which in turn contribute to successful implementation of the subregional activities. Subregional activities should be undertaken jointly by countries. A coordinating mechanism needs to be established (for example, a Regional Aquatic Animal Health Advisory Group) consisting of regional and international experts as appropriate.

The program (box 4.2) recognizes the importance of human capacity building, and this is addressed primarily in the form of training programs and workshops for the various areas of aquatic animal health. Development of research capacity is also important, but this generally involves postgraduate training and thus is to be addressed by the national governments.

Implementation Strategy

The implementation strategy will be done at two levels, that is, national level and regional level (see table 4.1). The implementation strategy emphasizes the need for national-level action to complete a number of essential activities that address national issues and priorities in support of the elements of the strategy. Completion of these national activities is essential to implementation the regional activities of the strategy, which tackle issues and priorities with a regional dimension.

As aquatic animal health management involves many issues that are transboundary in nature, an effective aquatic animal health protection program has to be supported by regional and international cooperation. Table 4.6 lists a number of activities that will be undertaken at the regional level and activities of the regional strategy whose completion is the responsibility of the national governments. In all cases regional activities will provide guidance toward accomplishing these national activities. National governments also have responsibilities toward completion of regional activities outlined in the Regional Program.

BOX 4.1: Results of An Analysis of Strengths, Weaknesses, Opportunities and Threats (SWOT) to the Successful Management of Aquatic Animal Health (AAH) in the Mozambique Channel (FAO 2014)

STRENGTHS

1. Organizational structure present at all levels of administration
2. Available human resources that can be trained on AAH
3. Presence of national aquaculture legislation
4. Stakeholder participation during preparation of legislation at all levels
5. Existence of fisheries research and training institutes for technology development and transfer
6. Presence of regulatory boards at the ministry level
7. Consistent government revenue collection from fisheries and aquaculture resources
8. Mozambique channel shares same ecological conditions and species, thus same AAH issues
9. Similar environmental legislations regarding aquaculture activities

WEAKNESSES

1. Low priority on AAH activities of government during sectoral program financial planning and budget allocation
2. Available legislations not clearly address issues pertaining to AAH and when addressed, are not fully operational nor enforced
3. Weak competence to perform disease diagnosis due to lack of AAH laboratory
4. Low capacity to undertake aquatic animal disease surveillance and reporting due to lack of expertise, facilities, and design/methods
5. Lack of comprehensive aquafarms' registration and database development (information system)
6. Lack of national pathogen list for Mozambique and Tanzania and subregional list of pathogens
7. Low capacity for emergency preparedness to aquatic disease outbreaks
8. Lack of national AAH action plan and strategies
9. Inadequate communication/networking on AAH issues
10. Inadequate compliance with international standards (for example, WTO SPS Agreement, OIE Code, and Diagnostic Manual)
11. Unavailability of vaccines against shrimp viral pathogens

OPPORTUNITIES

1. Ongoing public sector reform process
2. Existence of public-private sector partnership in shrimp aquaculture development and existence of well-defined working modality
3. Increasing need for aquaculture sector development for the growing human population and declining capture fisheries
4. AAH is a major sustainability issue
5. Enthusiastic stakeholders willing to participate in the development of the sector
6. Increasing domestic and export market demands for crustacean products
7. Except for WSSV, Subregion is still free from major shrimp pathogens
8. Governments recognize the weakness in the AAH management and strong willingness to improve

THREATS

1. Difficulty in recruiting qualified and experienced staff on AAH issues
2. Unavailability of budgetary allocation and when available, untimely disbursement of funds
3. Weather uncertainties accompanied with climate changes
4. Expected land and water resource user conflicts
5. Introduction of exotic, emerging and/or unknown shrimp pathogens
6. Weak implementation of good aquaculture practices, farm level biosecurity
7. Lack of cooperation between shrimp farmers
8. Reactive response/action to aquatic disease emergencies
9. Low priority given to biosecurity governance and AAH management

BOX 4.2: Mozambique Subregional Aquatic Animal Health Program Components, Elements, and Activities (FAO 2014)

COMPONENT 1—Governance
Element 1: Legislation and regulation
Activities:

1. Review and update of national legislation pertaining to all aspects of aquatic animal health and shrimp aquaculture
2. Harmonization of national legislation to international standards
3. Enhanced compliance to WTO SPS Agreement and trading partner requirements
4. Harmonization of implementation of WTO SPS Agreement at subregional level
5. Training on the implementation of international standards

Element 2: Policy and planning
Activities:

1. Develop national strategies on aquatic animal health (competent authority, national pathogen list, diagnostics, surveillance, use of veterinary medicines, emergency preparedness, prevention and management of risks from aquatic pathogens/diseases, aquatic animal health information system, responsible movement of live aquatic animals, risk analysis, capacity building, cooperation, and so forth) including guidance on development, implementation, and capacity development mechanisms
2. Regional priorities and collective action (minimum requirements and action on aquatic animal health)

COMPONENT 2—Subregional Preparedness/Response and Contingency Plan for Shrimp Disease Emergencies
Element 3: Emergency fund
Activities:

1. Prepare a concept note to define this element and detailed mechanisms/guidelines, estimating resources for implementation referring to existing mechanism or similar mechanisms in other sectors or create a mechanism specifically for aquatic emergencies. Assessment of national needs for diagnostic capability by an international expert assisted by national focal points. Enhanced compliance to WTO SPS Agreement and trading partner requirements

Element 4: Emergency response and contingency plans
Activities:

1. Training on the design and preparation of emergency response and contingency plans
2. Preparation of operational plans and technical manuals
3. Simulation exercise at farm level and national level (including planning and actual simulation)

COMPONENT 3—Diagnostics, Surveillance and Reporting
Element 5: Methods, design, and costing
Activities:

1. Harmonization of diagnostic methods and regional agreement on costs
2. Access to laboratory facilities that can provide quick and reliable diagnostic service
3. Recognition of a regional laboratory for reference, confirmation, and other assistance
4. Proficiency testing
5. Preparation of a regional list of pathogens
6. Design of a regional surveillance program
7. Training on implementation of diagnostics and surveillance

COMPONENT 4—Prevention and Management of Risks from Exotic, Emerging and/or Unknown Aquatic Pathogens
Element 6: Capacity building on best practices
Activities:

1. Training of shrimp farmers/producers/operators and government on good shrimp aquaculture and biosecurity practices
2. Training on risk analysis (different levels, public and private sectors)

Element 7. Minimum regional sanitary control
Activities:

1. Minimum biosecurity checklist (farm, national, regional levels) including legislation
2. Prepare regional minimum standards for importing crustaceans (live and products)

COMPONENT 5—Promotion of Sustainable Aquaculture Development and Responsible Investment
Element 8: Enabling environment
Activities:

1. Disseminate and exchange information about regional aquaculture practices (organic shrimp farming, certification, and so forth)
2. Promote aquaculture as a business model and provide guidance
3. Provision of aquatic animal health services and other services (extension, and so on)
4. Develop mechanisms for incentives and compensation and risk management schemes, for example, insurance
5. Coordinate effective actions to guarantee reliable business operation
6. Facilitate and assist in the formation of farmer association/cooperative/community-based organizations and provide support to relevant activities. Training on risk analysis (different levels, public and private sectors)

COMPONENT 6—Assessment of socioeconomic benefits/potential and risks, technical feasibility, and environmental impacts of further shrimp aquaculture development in the Indian Ocean subregion
Element 9: Assessment studies
Activities:

1. Technical feasibility studies, EIA or risk analysis of new ventures on shrimp aquaculture
2. Socioeconomic assessment of the impacts of aquatic pathogen introduction (for example, retrospective analysis of WSSV in Madagascar and Mozambique)
3. Socioeconomic assessment of the benefits of good aquaculture and biosecurity practices

COMPONENT 7—Institutional strengthening (human and financial resources, diagnostic and research infrastructure) and targeted capacity building on AAH
Element 10: Institutional strengthening
Activities:

1. Education on aquatic animal health (academic degrees)
2. Training (see also other sections)
3. Develop and/or improve national diagnostic and research infrastructure
4. Targeted capacity building (refer to other sections)
5. Manuals, operating procedures, protocols
6. Allocation of sufficient financial resources to aquatic animal health based on needs and priorities

COMPONENT 8 – Regional Collaboration, Communication, and Networking on Information and Shared Resources
Element 11: Aquatic animal health information system
Activities:

1. Regional web portal for an Aquatic Animal Health Information System covering all relevant information aspects of aquatic animal health
2. Early warning system
3. GIS for surveillance data
4. Regular and special/emergency meetings (all levels face-to-face, teleconference)

Element 12 : Shared resources
Activities:

1. Collaboration on shared resources (feed, laboratory, shrimp genetic resources, and so on)

TABLE 4.6: Summary of Mozambique Channel Subregional Strategy for Aquatic Biosecurity Showing Responsibility for Implementation (National or Subregional), Time Frame for Implementation (Short, Medium, or Long), and Priority Level (Low, Medium, or High) (FAO 2014).

PROGRAM ELEMENTS	ACTIVITIES	IMPLEMENTATION		TIME FRAME			PRIORITY		
		NATIONAL	SUB-REGIONAL	SHORT	MEDIUM	LONG	LOW	MEDIUM	HIGH
COMPONENT 1: BIOSECURITY GOVERNANCE									
1. Legislation and regulation	1. Review and update of national legislation pertaining to all aspects of AAH and shrimp aquaculture		X	■					■
	2. Harmonization of national legislation to international standards	X	X		■	■			■
	3. Enhanced compliance to WTO SPS Agreement and trading partner requirements		X		■	■		■	
	4. Harmonization of implementation of WTO SPS Agreement at subregional level		X		■	■		■	
	5. Training on the implementation of international standards	X	X		■	■		■	
2. Policy and planning	6. Develop national strategies on AAH	X	X	■					■
	7. Regional priorities and collective action (minimum requirements and action on AAH)		X	■	■	■		■	
COMPONENT 2: SUBREGIONAL PREPAREDNESS/RESPONSE AND CONTINGENCY PLAN FOR SHRIMP DISEASE EMERGENCIES									
3. Emergency fund	8. Prepare a concept note to define this element and detailed mechanisms/guidelines, estimating resources for implementation referring to existing mechanism or similar mechanisms in other sectors or create a mechanism specifically for aquatic emergencies	X							■
4. Emergency response and contingency plans	9. Training on the design and preparation of emergency response and contingency plans	X	X						■
	10. Preparation of operational plans and technical manuals	X	X		■				■
	11. Simulation exercise at farm level and national level (including planning and actual simulation)	X	X		■				■
COMPONENT 3: DIAGNOSTICS, SURVEILLANCE, AND REPORTING									
5. Methods design and costing	12. Harmonization of diagnostic methods and regional agreement on costs		X	■					
	13. Access to laboratory facilities that can provide quick and reliable diagnostic service		X	■	■	■			
	14. Recognition of a regional laboratory for reference, confirmation, and other assistance		X	■					
	15. Proficiency testing		X	■	■				
	16. Preparation of a regional list of pathogens		X		■	■			
	17. Design of a regional surveillance program		X	■					
	18. Training on implementation of diagnostics and surveillance	X	X	■					

COMPONENT 4: PREVENTION AND MANAGEMENT OF RISKS FROM EXOTIC, EMERGING AND/OR UNKNOWN AQUATIC PATHOGENS

PROGRAM ELEMENTS	ACTIVITIES	IMPLEMENTATION		TIME FRAME			PRIORITY		
		NATIONAL	SUB-REGIONAL	SHORT	MEDIUM	LONG	LOW	MEDIUM	HIGH
6. Capacity building on best practices	19. Training of shrimp farmers/producers/operators and government on good shrimp aquaculture and biosecurity practices	X	X						
	20. Training on risk analysis (different levels, public and private sectors)	X	X						
7. Minimum regional sanitary control	21. Minimum biosecurity checklist (farm, national, regional levels) including legislation	X	X						
	22. Prepare regional minimum standards for importing crustaceans (live and products)	X	X						

COMPONENT 5: PROMOTION OF SUSTAINABLE AQUACULTURE DEVELOPMENT AND RESPONSIBLE INVESTMENT IN SHRIMP AQUACULTURE

PROGRAM ELEMENTS	ACTIVITIES	IMPLEMENTATION		TIME FRAME			PRIORITY		
		NATIONAL	SUB-REGIONAL	SHORT	MEDIUM	LONG	LOW	MEDIUM	HIGH
8. Enabling environment	23. Disseminate and exchange information about regional aquaculture practices (organic shrimp farming, certification, and so forth)	X	X						
	24. Promote aquaculture as a business model and provide guidance	X	X						
	25. Provision of AAH services and other services (extension and so forth)	X							
	26. Develop mechanisms for incentives and compensation and risk management schemes, for example, insurance	X							
	27. Coordinate effective actions to guarantee reliable business operation	X	X						
	28. Facilitate and assist in the formation of farmer association/cooperative/community-based organizations and provide support to relevant activities.	X							

COMPONENT 6: ASSESSMENT OF SOCIOECONOMIC BENEFITS/POTENTIAL AND RISKS, TECHNICAL FEASIBILITY AND ENVIRONMENTAL IMPACTS OF FURTHER SHRIMP AQUACULTURE DEVELOPMENT IN THE INDIAN OCEAN SUBREGION

PROGRAM ELEMENTS	ACTIVITIES	IMPLEMENTATION		TIME FRAME			PRIORITY		
		NATIONAL	SUB-REGIONAL	SHORT	MEDIUM	LONG	LOW	MEDIUM	HIGH
9. Assessment studies	29. Technical feasibility studies, EIA or risk analysis of new ventures on shrimp aquaculture	X	X						
	30. Socioeconomic assessment of the impacts of aquatic pathogen introduction (for example, retrospective analysis of WSSV in Madagascar and Mozambique)	X	X						
	31. Socioeconomic assessment of the benefits of good aquaculture and biosecurity practices	X	X						

COMPONENT 7: INSTITUTIONAL STRENGTHENING (HUMAN AND FINANCIAL RESOURCES, DIAGNOSTIC AND RESEARCH INFRASTRUCTURE) AND TARGETED CAPACITY BUILDING ON AQUATIC BIOSECURITY (AQUATIC ANIMAL HEALTH)

PROGRAM ELEMENTS	ACTIVITIES	IMPLEMENTATION		TIME FRAME			PRIORITY		
		NATIONAL	SUB-REGIONAL	SHORT	MEDIUM	LONG	LOW	MEDIUM	HIGH
10. Institutional strengthening	32. Education on AAH (academic degrees)	X	X						
	33. Training	X	X						

TABLE 4.6: Summary of Mozambique Channel Subregional Strategy for Aquatic Biosecurity Showing Responsibility for Implementation (National or Subregional), Time Frame for Implementation (Short, Medium, or Long), and Priority Level (Low, Medium, or High) (FAO 2014) (*continued*)

COMPONENT 7: INSTITUTIONAL STRENGTHENING (HUMAN AND FINANCIAL RESOURCES, DIAGNOSTIC AND RESEARCH INFRASTRUCTURE) AND TARGETED CAPACITY BUILDING ON AQUATIC BIOSECURITY (AQUATIC ANIMAL HEALTH)

PROGRAM ELEMENTS	ACTIVITIES	IMPLEMENTATION		TIME FRAME			PRIORITY		
		NATIONAL	SUB-REGIONAL	SHORT	MEDIUM	LONG	LOW	MEDIUM	HIGH
	34. Develop and/or improve national diagnostic and research infrastructure	X	X	■	■	■		■	
	35. Targeted capacity building (refer to other sections)	X	X	■	■	■		■	
	36. Manuals, operating procedures, protocols	X	X	■	■	■		■	
	37. Allocation of sufficient financial resources to AAH based on needs and priorities	X	X	■	■			■	

COMPONENT 8: REGIONAL COLLABORATION, COMMUNICATION, AND NETWORKING ON INFORMATION AND SHARED RESOURCES

PROGRAM ELEMENTS	ACTIVITIES	IMPLEMENTATION		TIME FRAME			PRIORITY		
		NATIONAL	SUB-REGIONAL	SHORT	MEDIUM	LONG	LOW	MEDIUM	HIGH
11. Aquatic animal health information system	38. Regional web portal for an AAH Information System covering all relevant information aspects of AAH		X	■					■
	39. Early warning system		X	■					■
	40. GIS for surveillance data		X	■	■	■			■
	41. Regular and special/emergency meetings (all levels face-to-face, teleconference)		X		■	■			■
12. Shared resources	42. Collaboration on shared resources (feed, laboratory, shrimp genetic resources)		X		■	■			■

As many of these activities require considerable planning and financial support, more detailed proposals will be prepared separately. Key implementation activities include: 1) integration into national plans and other subregional or regional programs and, 2) focal points or national coordinators on aquatic animal health supported by a regional advisory group on aquatic animal health.

4.12 CONCLUSIONS

Cause of the Outbreak

The first epidemiological survey that was carried out in late 2011 demonstrated that shortly after the first outbreak at the Aquapesca farm WSSV was already widely distributed along the entire length of the Mozambican coast, infecting both shrimp and crabs. This is strong evidence that WSSV was already established in the Mozambique Channel before the first farm outbreak.

The genotype of the WSSV in the Mozambique Channel is closely related to that of the WSSV found in Saudi Arabia, and is genotypically distinct from WSSV found elsewhere in the world. This strongly suggests a common origin for the Saudi Arabian and Mozambique Channel strains of WSSV. The WSSV outbreak in Saudi Arabia began in January, 2011, 9 months before the outbreak in Mozambique. It seems likely that the WSSV in the Mozambique Channel originated in the Red Sea.

What is less clear is how WSSV was transported between the two areas. Both Mozambique and Madagascar prohibited the importation of live shrimp into their countries, so it seems unlikely imported live shrimp were the source of WSSV in the Mozambique Channel. It is possible that WSSV was somehow transported from the Red Sea to the Mozambique Channel, either in ship ballast water or by ocean currents. Another possibility is that shrimp fished from the Red Sea were transported to processing plants in Beira, Quelimane, Maputo, or Mahajanga.

The widespread distribution of WSSV in wild populations of shrimp along the coast of Mozambique, and the use of wild shrimp as

broodstock in the Nacala hatchery, strongly suggests that infected broodstock was the route by which WSSV infected the Aquapesca farm. Further support for this hypothesis is the fact that there was an outbreak of WSD in newly captured broodstock simultaneous with the outbreak on the Aquapesca farm. Broodstock brought to the hatchery before the initial outbreak also developed WSD. Before the WSSV outbreak in September, wild broodstock were not routinely quarantined and PCR-tested prior to being introduced into the hatchery. Another possibility is that the disease was introduced to the farm by infected wild crustaceans entering through the seawater pumping system.

It seems likely that the WSSV outbreak at the Aquamen EF shrimp farm also originated with either infected wild broodstock or infected carriers in the seawater system. Like the Nacala hatchery, the Aquamen hatchery relied on wild broodstock. The Aquamen hatchery normally quarantined, stress-tested, and PCR tested their broodstock prior to moving them into the hatchery. But they were relying on the LES to do their PCR testing. Due to lack of funding the LES discontinued PCR testing at the Aquamen facility several months before the WSSV outbreak. The lack of access to PCR testing may have resulted in the use of WSSV infected broodstock.

Contributing Factors at Farm Level

While two of the shrimp farming companies in Madagascar have shrimp breeding programs and stock SPF postlarvae, the rest of the shrimp industry in the region relies on wild broodstock. None of the companies using wild broodstock employed strict quarantine and PCR screening of their broodstock prior to the outbreak in 2011. Reliance on wild unscreened broodstock is perhaps the biggest disease risk factor for the aquaculture industry. Vertical transmission of viral diseases through infected wild broodstock provides a direct path for a viral disease to infect the shrimp on a farm and can result in widespread infection. Historically the use of wild broodstock and seedstock has fostered the spread of viral disease in shrimp aquaculture and in wild populations (Lightner 2009). The shrimp farming industry globally has recognized this and begun to make the transition from wild to domesticated broodstock and seedstock. This transition is critical to the long-term sustainability of shrimp farming.

All of the shrimp farms in the Mozambique Channel region are semi-intensive shrimp farms featuring large earthen ponds managed as open systems with high rates of water exchange. Little or no aeration is employed on these farms. Instead, water quality is maintained by exchanging up to 15 percent of the pond volume per day. This practice dramatically increases the risk of WSSV infecting the shrimp stocks in the ponds by horizontal transmission. Filtration of the incoming water is primarily done for the purpose of predator control using 500-micron screens. This mesh size, however, allows the passage of WSSV carriers such as crustacean larvae. The water distribution canals on these farms are rarely drained and contain considerable biomass of shrimp, crabs, ghost shrimp, oysters, and barnacles. This reservoir of susceptible hosts and mechanical hosts increases the vulnerability of farms to WSSV outbreaks.

One of the lessons learned from the viral pandemics of the last 20 years is that open systems are extremely vulnerable to disease outbreaks. Only by eliminating water exchange can the risk of horizontal transmission be eliminated. Substitution of aeration for water exchange is critical for farm biosecurity.

Prior to the WSSV outbreak in September 2011 no surveys of disease prevalence in wild crustacean populations had been conducted in Mozambique. A disease surveillance program was initiated in Madagascar in 2010, but was discontinued the following year due to funding issues. Disease surveillance programs provide early warning to shrimp farmers of the presence of pathogens in the nearby coastal environment, allowing them to take appropriate measures to minimize the potential for a catastrophic disease outbreak. The lack of surveillance programs in both countries resulted in the shrimp farms being unprepared when WSSV appeared in the Mozambique Channel. The two companies hit hardest by WSSV were the first companies to become infected in each country.

Both Mozambique and Madagascar now have surveillance programs in place. However, neither is sufficiently funded by the government or is as effective as it should be. The surveillance program in Mozambique was initially funded by the French Development Agency, and organized by the APCM with input from INIP and INAQUA. While the program is now funded by the Ministry of Fisheries, the government still has not taken full control of the program. In Madagascar there is no funding available for a surveillance program due to the governmental crisis. The private sector has had to carry out and fund its own surveillance programs. While

the efforts of the two companies conducting surveillance activities are commendable, the lack of coordination between the two programs has led to inefficiency. The surveillance data gathered by the two companies has not been available to other stakeholders in the country, reducing the overall value of the data gathered.

The recovery of the industry from the WSSV epidemic is dependent upon producers investing in improvements in the biosecurity of their operations. Farms that are currently dependent upon wild broodstock will need to invest in programs to develop domesticated SPF broodstock. Prevention of horizontal transmission will require investments in aeration systems, filtration systems, crab fencing, and bird netting. The total cost of these investments will be at least 5–10 million dollars for each farm. This cost may be too high for some of the farms to bear.

On the national level in each country, there were problems that limited the effectiveness of the governmental response to the outbreak. Prior to the WSSV outbreak neither Mozambique nor Madagascar had developed a comprehensive aquatic animal health policy, or functional institutions in place to provide a coordinated response to the crisis.

Mozambique

In Mozambique the regulatory framework for the aquaculture industry is still being developed. INAQUA, the government agency responsible for overseeing the aquaculture industry was only created in 2009 and when the WSSV outbreak occurred in 2011 the agency was still in the process of recruiting personnel to complete its structure (Le Groumellec 2011). INIP is the designated Competent Authority for aquatic animal health, but lacks a reference laboratory or personnel with training in aquatic animal disease diagnostics.

There is a lack of legislation regarding aquatic animal health clearly defining the roles each stakeholder (Baloi and Le Groumellac 2012). The WSSV crisis made it clear to all stakeholders in Mozambique the importance of developing a national strategy for aquatic animal health supported by legislation. Work began immediately on drafting a set of aquatic animal health regulations and a national strategy for dealing with WSSV and other disease outbreaks. The process, however, is time-consuming and nearly 2 years after the initial outbreak of WSSV neither piece of legislation has been approved. Even after the legislation is approved it will take more time for the new organizational structure to become fully functional.

Madagascar

In Madagascar, the regulatory framework for the aquaculture industry is slightly better developed than in Mozambique, at least on paper. There is a national pathogen list for aquatic animal diseases, and there is a legislated aquatic animal health policy. Madagascar also has a designated official reference laboratory for aquatic animal diseases. Nevertheless, the lack of funding for aquatic animal health programs has crippled ASH and LES to the point that they are unable to function in a meaningful capacity. When the WSSV crisis struck the country in 2012, the Malagasy government was unable to mount a coordinated response to the disease outbreak.

4.13 RECOMMENDATIONS

At the conclusion of the Regional Workshop on White Spot in the Mozambique Channel, workshop participants identified four main areas to be addressed by the region:

1. Development of national and regional biosecurity protocols, including procedures for normal operation, procedures to respond to disease outbreaks, and procedures for restart of farms following a disease outbreak
2. Transition from the use of screened wild broodstock to the use of SPF broodstock and eventually to broodstock genetically selected for disease resistance
3. Design and implementation of national disease surveillance programs with collaboration between Competent Authorities of countries in the region and sharing of results between all stakeholders
4. Promotion of regional cooperation between all stakeholders by setting up technical and strategic committees to address region-wide aquatic animal health issues such as regional breeding programs, disease surveillance, and regional responses to disease outbreaks

The following are some specific measures recommended by the Expert Team to promote aquatic biosecurity in the region:

Recommendations for Producers

1. **Develop a Regional Breeding Center to produce SPF broodstock**

   The replacement of wild broodstock with SPF domesticated should be given the highest priority. A single breeding

center for the entire region would be the most economical alternative. Without a base to build upon, it typically takes 2 years to develop an SPF population and several additional years of captive breeding to achieve domestication. However, two farms in the region already have SPF breeding centers that can serve as a foundation for a regional breeding center. If there is cooperative effort on the part of all stakeholders in both Mozambique and Madagascar, the entire region could have access to SPF seedstock within a year.

For Mozambique, the quickest route for the replacement of wild broodstock would be to permit the importation-certified SPF stocks from Madagascar. This is prohibited under current law. Unless this law is modified to permit the importation of certified disease-free stocks, Mozambique will have to develop its own SPF breeding program from scratch.

2. **Breed for WSSV-resistance**
   After the establishment of SPF populations in the regional breeding center, priority should be given to breeding for resistance to WSSV. The feasibility of this strategy has been demonstrated with *L. vannamei*. With a well-designed breeding program, gains in WSSV resistance of 2–5 percent per generation should be possible.
3. **Follow strict PCR screening procedures if use of wild broodstock is unavoidable.**
   If wild broodstock must be used, they should be quarantined in individual tanks and individually tested by PCR. Females should be tested by PCR and histology after each spawn, and PLs should be PCR-tested prior to sending them to the farm.
4. **Avoid stocking during the cold season**
   Outbreaks of WSD are much more likely to occur when water temperatures are low. Avoiding stocking during the coldest months of the year has proven to be an effective strategy for mitigating WSD outbreaks. The strategy is most effective when all shrimp farms in a region dry out during the cold season.
5. **Upgrade farm biosecurity to minimize horizontal transmission.**
   Farm biosecurity must be upgraded to minimize risk of mortality due to horizontal transmission of WSSV. Various technologies are available depending on the appropriate balance of risk tolerance and capital availability at each facility. The risk reduction associated with a particular strategy must be weighed against its cost. For example, installing a self-cleaning microscreen system to filter incoming seawater to less than 100 microns before it enters the distribution canal might improve biosecurity to a greater extent than passing the water through a static 200-micron filter bag as it enters the pond, but the cost is at least 30 times higher. For a farm that has limited capital resources, the most biosecure option may not make sense financially. Farms that are producing for organic markets have other constraints on the allowable technologies that they can adopt. So clearly, one size does not fit all. Each farm will have to develop a biosecurity plan that is appropriate for their situation. Collaboration between the individual farms, the producer's associations and the Competent Authority would be helpful in defining best practices to achieve a minimum standard of biosecurity.
   Explore alternatives for providing financial assistance to farms for biosecurity upgrades
   An outbreak of WSSV at a given farm in the region will heighten the prevalence of the disease in the environment and increase the risk of transmission to others. Consequently, it is in the interest of all the stakeholders for farms to upgrade their biosecurity infrastructure. Therefore there should be a concerted effort on the part of all stakeholders to identify mechanisms to finance biosecurity upgrades.

Recommendations for the Public Sector

1. **Review national legislation pertaining to aquatic animal health policy**
   Aquatic animal health policy should be written into national law. The law should clearly identify the institutions responsible for overseeing aquatic animal health policy and should define the relationships between each institution. The legislation should identify who in the government will assume the role of Competent Authority for aquatic animal health and clearly define the powers and authority for that position. The laws pertaining to aquatic animal health should define policies concerning import and export of aquatic animals, quarantine and health certification procedures, and responses to disease outbreaks. New and existing legislation should be reviewed to make sure it is consistent with international standards and obligations, such as the OIE's International Aquatic Animal Health Code.
2. **Designate a National Reference Laboratory for Aquatic Animal Health**
   Each country should designate a National Reference Laboratory for aquatic animal health and provide sufficient funding to equip the laboratory with state of the art equipment for histopathology and PCR testing. Lab personnel should receive the training needed to accurately diagnose the range of aquatic animal diseases, and labs should participate in ring test proficiency exercises. The laboratories should be adequately staffed to enable quick turn-around times on sample processing.

3. **Develop national aquatic disease surveillance programs to OIE standards**
   Disease surveillance programs should be coordinated and funded by the ministry of the Competent Authority, rather than being left to the initiative of the private sector. Surveillance programs provide early warning of disease hazards and provide producers with the opportunity to take early action to avoid catastrophic losses. Results of surveillance testing should be made public quickly to all national and regional stakeholders. A website should be created for posting of results. The creation of a website for surveillance data should be given high priority so that the surveillance data from the private sector surveillance efforts in Madagascar and the surveillance program in Mozambique can be rapidly shared among all stakeholders.
4. **Develop national response plan for aquatic animal health emergencies**
   Each country should develop a national response plan for aquatic animal health emergencies. The Australian AquaVetPlan (DAFF 2005) is an excellent model that many countries have used for crafting their own aquatic animal health plans.
5. **Strengthen partnership between public and private sectors**
   Long-term sustainability and growth of the shrimp industry in the Mozambique Channel can only be achieved in a biosecure environment. National and regional biosecurity requires close cooperation of producers and national institutions responsible for coordinating and implementing aquatic animal health policy. The producer associations in each country (APCM in Mozambique and GAPCM in Madagascar) are the interface between the producers and the government ministries. Priority should be given to promoting collaboration between the producer associations and the government ministries in the development of national biosecurity policies and programs. A good starting point would be to schedule quarterly meetings between the producer associations and the government ministries responsible for aquatic animal health. Strategic and technical committees composed of representatives from both the public and private sector would be very productive ways to identify biosecurity strategies that will benefit the entire sector. The private sector representatives would provide the technical expertise and intimate knowledge of the needs of private sector. The public sector representatives would provide expertise on program organization and management, and would make sure the public interest is represented. Building cooperative working groups would build trust between the public and private sector and would ensure that all stakeholders are working together toward a common goal.

Regional Level Cooperation

As an ultimate goal, the national AAH plans of Mozambique and Madagascar should be integrated to form a Regional AAH plan. The regional plan would identify mechanisms for cooperation between the Competent Authorities in each country. An excellent starting point for the regional plan would be to schedule regular meetings (annual or twice a year) between stakeholder groups of both countries to share information and to discuss cooperative projects. Two areas where regional cooperation will be critical are in the sharing of surveillance data and the establishment of a regional breeding center.

The white spot crisis has illustrated that, despite its geographic isolation, the shrimp aquaculture industry in the Mozambique Channel region (Mozambique, Madagascar, and Tanzania) is vulnerable to epizootic disease outbreaks. It must be recognized that all of the shrimp producers in the Mozambique Channel region operate on a common body of water, and that the biosecurity of each farm is dependent on the biosecurity practices of all of the other farms and shrimp processors in the region. A coordinated regional response to the white spot disease outbreak is needed to allow the shrimp industry to return to profitability. A regional approach to biosecurity is also the best defense against future introductions of other OIE listed diseases.

In April 2013 the FAO convened a workshop in Maputo for the purpose of developing a subregional strategy to improve aquatic animal health and biosecurity in the Mozambique Channel. The participants in this workshop included representatives from Mozambique (INAQUA, INIP, and the APCM), Madagascar (ASH), Tanzania (National Animal Aquatic Health Coordinator), and the FAO Aquaculture Service. At the conclusion of the workshop the participants drafted a document outlining a strategy for improving aquatic biosecurity and aquatic animal health for the Mozambique Channel subregion. The strategy identifies policy measures to be implemented at the national and regional level to promote aquatic animal health in the region. While additional work will be needed

to fill in the details, the plan provides an excellent framework for addressing the biosecurity needs of the region. Rather than propose a separate Regional Biosecurity Plan, the World Bank Mission Expert Team endorses the regional biosecurity strategy proposed by the FAO working group, but would like to recommend the following *additional* program activities:

Governance

1. Legislation should clearly identify the Competent Authority, and a National Reference Laboratory for aquatic animal disease diagnoses.
2. Each country in the region should develop a detailed Aquatic Animal Health Plan, identifying the Competent Authority, National Reference Laboratory, listed pathogens, key biosecurity policies, and emergency plans for disease outbreaks.
3. The National Plans should specify how information on aquatic animal health will be shared between the Competent Authorities of all the countries in the subregion.

Preparedness/Response and Contingency Plan for Shrimp Disease Emergencies

1. Clear procedures should be developed specifying the actions farms must take when a listed disease is diagnosed, including immediate discontinuation of water exchange, procedures for destruction and disposal of existing shrimp stocks, and disinfection of the farm.
2. The criteria for shrimp farms to start back up again following a disease outbreak should also be clearly identified.

Diagnostics, Surveillance, and Reporting

1. Surveillance programs for OIE-listed shrimp pathogens should be a cooperative effort undertaken by the governments of the Mozambique subregion countries.
2. A regional surveillance program should be designed with the assistance of an OIE-designated consultant to ensure both wild and farmed populations are effectively sampled. A sampling program should also be developed for shrimp processing facilities.
3. A regional authority should be designated to oversee the surveillance program, including sample collection, sample submission, disease diagnostic work, collection and analysis of data, and reporting of the findings.
4. National Reference Laboratories should be designated for each country in the subregion.
5. Reference Laboratories should be provided with state-of-the-art diagnostic equipment with sufficient sample processing capacity to enable timely processing of samples and reporting of results.
6. Reference Laboratories should participate in ring-testing exercises to validate the accuracy and reproducibility of the laboratories' diagnostic procedures.
7. Results of the surveillance program should be posted quickly to a website to permit immediate access by all stakeholders. Data collected by privately sponsored surveillance programs should also be posted to this website. Positive results should generate alerts to be sent out to the competent authority and to designated representatives on each farm.
8. Designation of the subregion or zones within the subregion as disease free should be based on evidence provided by sample evidence and in accordance with OIE standards.
9. Funding of the surveillance program is the responsibility of the governments of the subregion countries. However, a concept note should be prepared for possible funding by international agencies and/or private donors detailing the costs, needs, and benefits of the surveillance program.

Prevention and Management of Risks from Exotic, Emerging and/or Unknown Aquatic Pathogens

1. The shrimp industry must make the transition from reliance on wild broodstock to captive-reared SPF broodstock. During the transition period, wild broodstock should be used only if they have been shown to be disease free by a rigorous quarantine and PCR testing protocol.
2. A shrimp breeding center should be established to produce SPF broodstock and seedstock and made available to all shrimp farms in the Mozambique Channel subregion. This breeding center should be developed as a cooperative effort of the governments and shrimp producers. (Note: The details of where the breeding center is located, how it is managed, and how it is funded should be determined by a working group consisting of public and private sector representatives from each country in the subregion.)
3. As a long-term strategy, SPF broodstock at the breeding center should be selected for resistance to WSSV.
4. A minimum standard for farm biosecurity should be developed by a working group to include public and private stakeholders from each country in the subregion. (Note: It should be recognized that every farm is different and

that biosecurity plans must be tailored to the needs and resources for each farm.)

5. Each farm should develop and implement a biosecurity plan. The Competent Authority should review the biosecurity plan for each farm to make sure the plan meets the minimum standards for biosecurity as defined by the sub-regional working group.
6. Prepare regional minimum standards for importing crustaceans (live and products).
7. Legislation should include an exception to the ban on importation of live aquatic animals to allow for the importation of veterinarian-certified SPF seedstock and broodstock from other countries in the Mozambique Channel subregion.

Promotion of Sustainable Aquaculture Development and Responsible Investment in Shrimp Aquaculture (No changes or additions recommended.)

Assessment of Socioeconomic Benefits/Potential and Risks, Technical Feasibility and Environmental Impacts of Further Shrimp Aquaculture Development in the Indian Ocean Subregion (No changes or additions recommended.)

Institutional Strengthening (human and financial resources, diagnostic and research infrastructure) and Targeted Capacity Building on Aquatic Biosecurity (aquatic animal health)

1. Training should be provided to Reference Laboratory technicians in both PCR and histological procedures so that they are able to accurately diagnose all of the OIE-listed aquatic animal diseases.
2. Budgets for agencies responsible for AAH should include the cost of maintaining surveillance programs, Reference Laboratories, and other costs associated with maintaining a pro-active Aquatic Animal Health Program.

Regional Collaboration, Communication, and Networking on Information and Shared Resources

1. Regional strategic and technical committees should be organized with stakeholder representatives from all countries in the subregion to ensure regional collaboration and information sharing in the development of AAH national plans, and regional surveillance programs.
2. The regional strategic and technical committees should meet on a quarterly basis to promote communication between stakeholder groups and to review progress on regional AAH initiatives.
3. Disease outbreaks within the region will require a region-wide response. Regional strategic and technical committees should develop procedures for a regional response to aquatic animal health emergency.

The expert team believes that with the addition of the recommended activities, the strategy for improving aquatic biosecurity for the Mozambique Channel provides an outstanding blueprint for recovery of the shrimp farming industry from the white spot disease crisis and for preventing future disease outbreaks.

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

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From review of case study findings, it is clear that there are several key structural and behavioral attributes of the aquaculture industry that make it vulnerable to disease. It is also clear that, while the species, production systems, and names of the participants and institutions involved in the operation and regulation of aquaculture vary from place to place, the science and logic that can reduce the incidence and severity of disease are common throughout the industry.

Conditions that lead to disease include: (1) close proximity among farming operations and/or contiguous water supply and discharge; (2) unregulated transfer of culture animals, animal products, and/or gametes among farms and from sites outside of the farming area; (3) high levels of stress in farmed animals resulting mostly from crowding; (4) lack of adherence to on-farm sanitary protocols; (5) inadequate government veterinary services; and (6) failure of farmers to share information and cooperate in collective action to respect best management practices.

Corrective measures to avoid or moderate diseases in aquaculture respond directly to the causative conditions: (1) regulate the density of farms within a designated zone so as to avoid sharing of water inputs and outfalls; (2) quarantine and carefully control movement of culture animals and other biological materials into the zone and between farms once introduced; (3) adoption of best aquaculture practices at farm level to reduce stress and improve animal welfare; (4) introduce and respect basic sanitary measures at the farm level; and (5) structure dialogue among farmers and between government and farmers to improve knowledge and compliance, while reducing free ridership.

The aquaculture industry should recognize that it will take more than laws, regulations, and improved practices to prevent another disease crisis. The values and attitudes of those involved in the industry are a crucial component of preventing a future problem. Cooperation between groups is essential due to the nature of the shared water bodies used by closely interconnected producers.

Lessons Learned

Losses to the aquaculture industry globally are estimated by Food and Agriculture Organization (FAO) at about US$6 billion annually. The infectious salmon anemia (ISA) outbreak in the Chilean salmon farming industry cost US$2 billion dollars and 20,000 jobs. The early mortality syndrome (EMS) outbreak in the Mekong Delta is costing what are mostly small-scale producers about US$800 million per year that they cannot afford, and this does not include the unknown number of jobs lost in the rest of the shrimp value chain. Losses from white spot syndrome virus outbreaks in Asia were estimated at US$6 billion during outbreaks in 1992/1993 and US$1–2 billion during 1999 outbreaks in Latin America.

Diseases are ubiquitous and pretending that it will not happen because it has not happened is not rational. Suiss-RE, a major agricultural crop insurer, calculates that the average insurance loss ratio for aquaculture over the period 1992–2012 was 65 percent and disease accounted for 20 percent of that (in the relatively well-managed salmon farming industry). Most aquaculture disease outbreaks have occurred in developing countries where over 90 percent of aquaculture takes place, reducing revenues, eliminating jobs, threatening food security and undermining development goals. The generally small-scale and rural nature of aquaculture in developing countries means that the vast majority of diseases go undiagnosed, untreated and undocumented, imposing an enormous burden on communities working to escape poverty.

The impressive technical and commercial success of the global aquaculture industry has not been accompanied by matching

research, monitoring, and regulation to guard against foreseeable biological risks. Government investment in veterinary services, environmental management, and establishing a dialogue with industry lags behind growth in production.

The impacts of large-scale disease outbreaks affect employment and economic growth across the entire value chain, region, and sometimes country, justifying government engagement in preventing and managing the health of the aquaculture sector.

Spread of pathogens is facilitated by high concentration of farms and poor husbandry and disease control measures. Reducing fish stocking rates and adopting best practices can reduce fish stress, and the incidence and impact of disease outbreaks.

A working public-private coordinated effort is needed to both avoid and respond to disease crises. When bodies of water are shared, regulations are required to ensure that all parties involved are good environmental stewards and neighbors. The larger the industry, the more risks there are and the harder it is to control a problem. So, it is critical to have a system in place to ensure sound industry practices, and early detection and rapid control of a problem if one occurs.

Among key stakeholders in aquaculture disease management is the financial sector. Financiers who understand aquaculture are essential for the industry to weather disease outbreaks.

Rapid returns to investment in disease management are possible. Lowering the densities of fish in a cage and cages in an area can increase growth and survival rates to more than compensate for reductions in fingerlings stocked per cubic meter.

As aquaculture continues to grow, a new regulatory framework is needed. Important issues to address include:

- Mechanisms to avoid overconcentration of farming activity in a given area.
- Improved pathogen dispersion control strategies.
- Boundary definition of production zones.
- Definition of zone carrying capacity.
- Surveillance programs to detect and/or predict new environmental and disease issues before they can affect the entire industry.

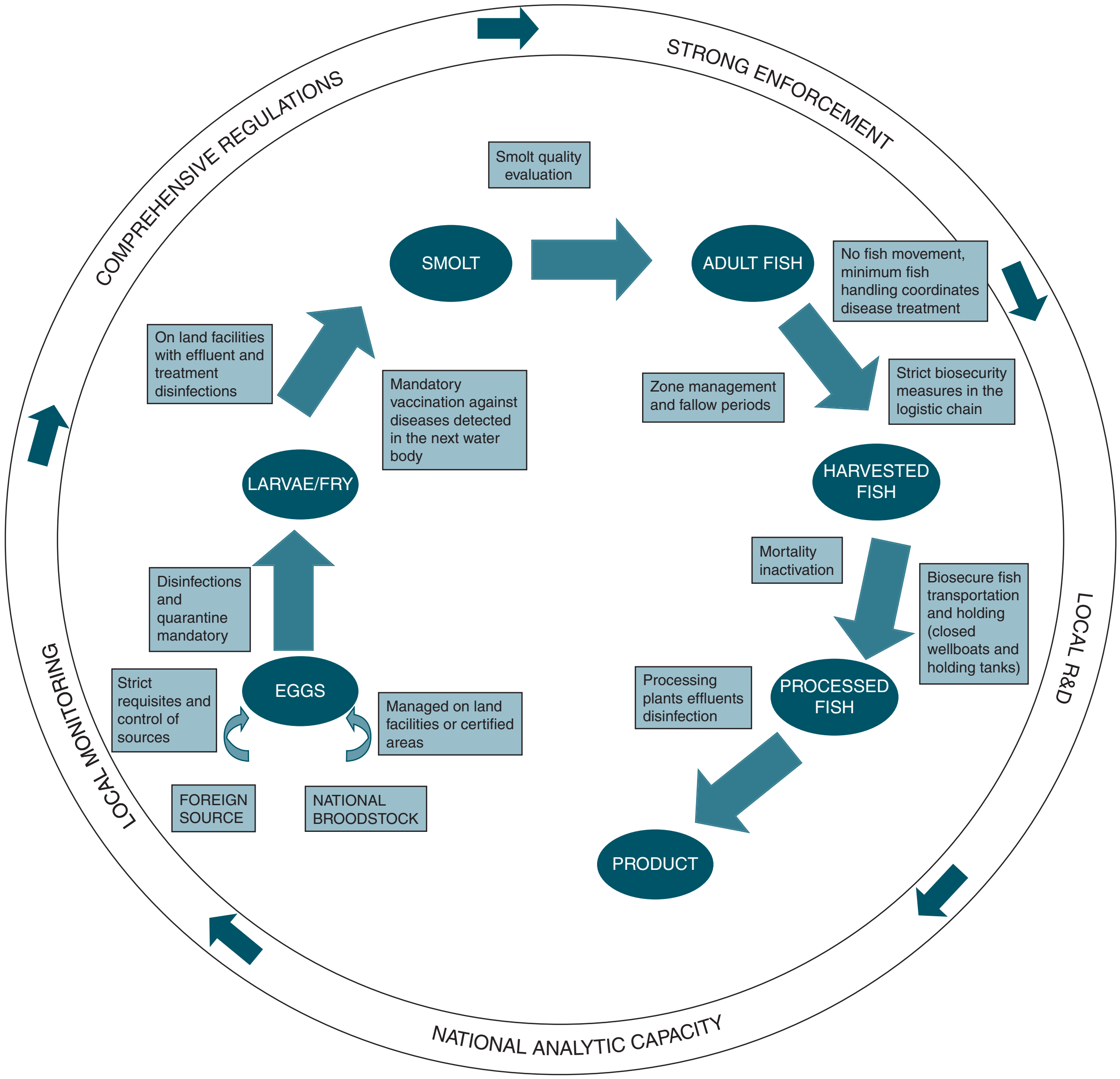
The overarching lesson is that successful aquaculture depends on the capacity of biological systems to support it. Defining the capacities of bodies of water is essential in order to regulate the number of farms and to set limits on the maximum production in farming areas. Unless this is done, conditions will deteriorate leading to poor fish performance and eventually to disease.

These lessons are broadly true of all the case studies examined. As applied to the Chilean experience they are graphically summarized in figure 5.1. To reiterate the key points:

- Government and industry must develop national/local R&D programs to provide timely information to support effective regulations and enforcement.
- Development of a biosecurity system covering all sectors of the value chain. This system should target preventing the entry of pathogens. The system should also consist of a contingency plan for controlling the dispersion of pathogens should the prevention plan fail, which includes early detection within the country.
- The dynamics and biological carrying capacities of the environments hosting aquaculture activities should be understood in order to prevent deterioration that leads to fish distress and disease.
- This understanding should allow the establishment of effective zone management programs and provide the basis for coordinated actions among users, such as fallow periods, programmed treatments, surveillance programs, and so forth.
- Prioritize practices based on fish welfare and close monitoring of key performance indicators such as levels of sea lice infestation, frequency of antibiotic treatments for bacterial disease, mortality, growth, food conversion ratio, and harvest yield per smolt stocked.
- Reduce handling and use of drug treatments in order to improve long-term farming sustainability and market acceptance of the products.
- Good communication between all industry stakeholders and government must be maintained to ensure issues are dealt with early and all parties involved are kept abreast of the situation.

As a first step in addressing constraints to aquaculture disease management, a review of the existing aquatic veterinary services

FIGURE 5.1: Essential Macro and Micro Components Extracted from the Handling of the ISA Chilean Case for a Safer and Long-Term Industry (Alvial 2011)



is recommended. The World Organization for Animal Health (OIE) conducts standardized reviews of veterinary services that can identify opportunities to improve performance and capacity, and collect data for cost-benefit analysis of investments in improved biosecurity.

Estimation of the carrying capacity of the watershed or water body in which aquaculture is being conducted requires spatial mapping of production systems and their related hydrology. As the single greatest constraint to proper disease management in aquaculture is the lack of cohesion and cooperation among producers, encouraging management planning at the ecosystem, rather than farm, level serves not only to define the space over which biosecurity rules should be implemented, but creates a context in which farmers may be better able to understand the need for collective action.

Cost-Benefit of Biosecurity

Required investments in biosecurity to minimize the risk of disease outbreaks will vary according to place and scale. The need for improved diagnostic and surveillance capacity of national veterinary services is one common element among all case studies. The establishment of a national and/or regional platform for communication between government and farmers is also important, but less costly. Apart from these government investments, in Chile, major costs for salvaging the salmon industry were associated with relocation and restocking of farm installations, costs borne mostly by the private sector.

In Vietnam (and Southeast Asia more generally), the farm level investment needed to manage EMS is not yet known, but government investment in affordable three-phase electricity would help lift constraints to the ability of lower income farmers to reduce their dependence on high levels of water exchange. Providing assistance to establish a forum for communication and cooperation among the hundreds of thousands of farmers that share a contiguous water supply will also improve monitoring of, and compliance with, farm-level and regional biosecurity protocols.

Along the Mozambique Channel, farm-level improvements in biosecurity have been estimated at between US$6 and 14 million, depending upon the level of security. A basic system includes stocking specific pathogen-free (SPF) PLs, crab fencing, bird netting, probiotic usage, and structures to allow drainage of seawater distribution canals. Reducing stocking rate to allow reduced water exchange is probably unprofitable. The addition of aeration plus bag filtration increases productivity, reduces overall operating costs, and improves the profit margin. Net returns per kg of shrimp produced are estimated at US$1.25/kg with no biosecurity plan and US$2.00/kg under this strategy. The most biosecure strategy, in which aeration and microscreen drum filtration is used, is very capital intensive with an expected investment cost of about US$14 million dollars for a 400 ha farm. Despite the high cost, the profit per kg of shrimp is reduced by only US$0.12/kg.

Best Aquaculture Practices

Some of the outcomes of the disease outbreak and, finally, recovery reflect failure to respect basic principles of aquaculture. While not an exhaustive list of best aquaculture practices, the three case studies highlight particular issues that are sometimes not relevant to farm practice (and therefore not easily controlled by farmers) and ignored by regulators who are happy to see an aquaculture industry growing and have limited resources to invest in the protection of these investments. One might sum up by invoking the old adage: *An ounce of prevention is worth a pound of cure.*

- **Physical isolation does not assure biosecurity.**
  By virtue of its physical isolation, the shrimp industry surrounding the Mozambique Channel had been free from OIE-listed diseases. This freedom from disease resulted in many of the farms lagging behind the rest of the world in the adoption of biosecure production practices such as the elimination of dependence on wild broodstock, and the continued reliance on high rates of water exchange to manage water quality in the shrimp ponds. When WSSV did reach the area, these farms were vulnerable.
- **High rates of water exchange are a major risk factor for horizontal transmission.**
  Substitution of aeration for water exchange can be cost effective with only modest intensification of production.
- **Breeding programs to produce SPF disease-resistant stocks should be a regional priority.**
  The reliance on wild broodstock is one of the biggest biosecurity risks for aquaculture. However, it is not economical or feasible for each individual producer to maintain their own breeding center to produce SPF stocks. Development of a regional breeding center is a cost-effective strategy for eliminating the use of wild broodstock for all producers in the region.
- **Surveillance programs are critical for national biosecurity.**
  The fact that WSSV and EMS were found in a high percentage of the samples taken in shortly after the first outbreak suggests that the diseases may have been present in the area for months before the first outbreak. If a national surveillance program had been sampling the wild populations on a regular basis before the outbreak occurred, producers could have taken appropriate measures to upgrade biosecurity before disease appeared on their farms.
- **Strong national aquatic animal health policies and institutions are critical for national biosecurity.**
  The absence of strong national aquatic animal health (AAH) policies and institutions increases the vulnerability of the

region to epizootic disease outbreaks. Aquatic animal health (AAH) policies should clearly define the responsibilities of the various stakeholders in maintaining national biosecurity, as well as the procedures that must be followed when a disease outbreak does occur. A dedicated AAH service could be more cost-effective than a wholesale restructuring of the complete veterinary system in countries where fish are disproportionately important to the economy.

- **National and regional biosecurity requires cooperation of all stakeholders.**
  The investment required to manage farm biosecurity increases with disease prevalence. Consequently, it is in the interest of all stakeholders to avoid outbreaks in the region through implementation of biosecurity practices that meet or exceed minimum standards. Weak biosecurity on individual farms weakens the biosecurity for all of the farms in the region. Producer associations and governments should work together to develop standards for minimum biosecurity practices and assure that they are implemented at each facility.

The primary lesson of these case studies is that aquaculture disease management goes beyond the limits of individual farms and requires a collective zone management approach. The salmon industry has, sometimes painfully, learned this lesson and is now raising itself to a new, more sustainable, level in Chile and elsewhere. Globally, shrimp farmers and other aquaculture producers who share a waterbody with their neighbors, need to reflect on the examples of Chile, Vietnam, Mozambique, and Madagascar and take steps to improve coordination among farmers and between the farming community and regulators so as to better manage the ecosystems in which they operate. Only through an ecosystem approach can the industry reduce volatility, improve profitability, and approach greater sustainability.

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