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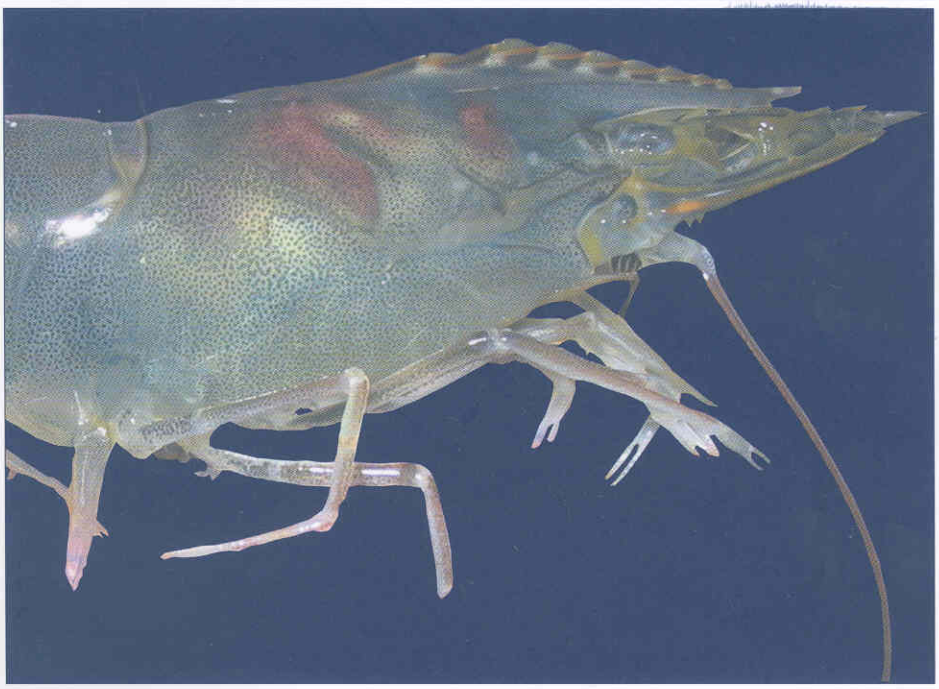
Introductions and movement of *Penaeus vannamei* and *Penaeus stylirostris* in Asia and the Pacific



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Introductions and movement of *Penaeus vannamei* and *Penaeus stylirostris* in Asia and the Pacific

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Abbreviations and acronyms

ADB	Asian Development Bank
AFFA	Agriculture, Forestry and Fisheries Australia
APEC	Asia-Pacific Economic Cooperation
APHIS	Animal and Plant Health Inspection Service of the USA
AQIS	Australian Quarantine and Inspection Service
BFAR	Bureau of Fisheries and Aquatic Resources of the Philippines
BMNV	Baculoviral Midgut Gland Necrosis Virus
BMP	Best Management Practice
BP	Baculovirus Penaeii
CCRF	FAO Code of Conduct for Responsible Fisheries
CNA	Camara Nacional de Acuacultura
CTSA	Center for Tropical and Subtropical Aquaculture
DIAS	FAO Database of Introduced Aquatic Species
DNA	Deoxyribonucleic Acid
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency of the USA
FAO	Food and Agriculture Organization of the United Nations
FCR	Food Conversion Ratio
GAA	Global Aquaculture Alliance
GAV	Gill Associated Virus
GIS	Geographic Information System
GSMFC	Gulf States Marine Fisheries Commission
h2	Heritability coefficient
HACCP	Hazard Analysis Critical Control Point
HH	High Health
ICES	International Council for the Exploration of the Sea
IHHNV	Infectious Hypodermal and Haematopoietic Necrosis Virus
INP	Instituto Nacional de Pesca, Ecuador
IRA	Import Risk Analysis
JSA	Joint Sub-committee on Aquaculture
LOVV	Lymphoid Organ Vacuolization Virus
LPV	Lymphoid Parvo-like Virus
MBA (PVB)	Monodon Baculovirus
MCMS	Mid Crop Mortality Syndrome
MOFI	Ministry of Fisheries of Viet Nam

MOV	Mourilyan Virus
MPEDA	Marine Products Export Development Agency of India
MSFP	Marine Shrimp Farming Program of the USA
MT	Metric tonnes
NACA	Network of Aquaculture Centres in Asia-Pacific
NHP	Necrotising Hepatopancreatitis
NMFS	National Marine Fishery Service (of Dept of Commerce)
NPV	Nuclear Polyhedrosis Baculovirus
OIE	World Organisation for Animal Health
PCR	Polymerase Chain Reaction
PL	Postlarvae
ppb	parts per billion
ppm	parts per million
ppt	parts per thousand
RDS	Runt Deformity Syndrome
REO	Reo-like Viruses
RNA	Ribonucleic Acid
SEMERNAP	Secretaria del Medio Ambiente y Recursos Naturales y Pesca, Mexico
SMV	Spawner-isolated Mortality Virus
SOP	Standard Operation Procedure
SPF	Specific Pathogen Free
SPR	Specific Pathogen Resistant
SPS	Sanitary and Phytosanitary Agreement
TBT	Agreement on Technical Barriers to Trade
TFRC	Thai Farmers Research Center Co.
TSV	Taura Syndrome Virus
USA	United States of America
USDA	United States Department of Agriculture
USDC	United States Development Council
UV	Ultra Violet
WB	World Bank
WWF	World Wildlife Fund (Worldwide Fund for Nature)
WSSV (SMBV)	White Spot Syndrome Virus
WTO	World Trade Organization
YHV (YBV)	Yellow Head Virus

1. Executive summary

Both *Penaeus vannamei*[1] and *P. stylirostris* originate on the Western Pacific coast of Latin America from Peru in the south to Mexico in the north.

They were introduced from the early 1970s to the Pacific Islands, where research was conducted into breeding and their potential for aquaculture. During the late 1970s and early 1980s they were introduced to Hawaii and the Eastern Atlantic coast of the Americas from South Carolina and Texas in the North to Central America and as far south as Brazil.

The culture industry for *P. stylirostris* in Latin America is largely confined to Mexico, but *P. vannamei* has become the primary cultured species in the Americas from the USA to Brazil over the past 20-25 years. Total production of this species in the American region probably amounted to some 213 800 metric tonnes, worth US$ 1.1 billion[2] in 2002.

P. vannamei was introduced into Asia experimentally from 1978-79, but commercially only since 1996 into Mainland China and Taiwan Province of China, followed by most of the other coastal Asian countries in 2000-01. Experimental introductions of specific pathogen free (SPF) "supershrimp" *P. stylirostris* have been made into various Asian countries since 2000, but the only country to develop an industry to date has been Brunei.

Beginning in 1996, *P. vannamei* was introduced into Asia on a commercial scale. This started in Mainland China and Taiwan Province of China and subsequently spread to the Philippines, Indonesia, Viet Nam, Thailand, Malaysia and India. These introductions, their advantages and disadvantages and potential problems are the focus of this report.

China now has a large and flourishing industry for *P. vannamei*, with Mainland China producing more than 270 000 metric tonnes in 2002 and an estimated 300 000 metric tonnes (71 percent of the country's total shrimp production) in 2003, which is higher than the current production of the whole of the Americas.

Other Asian countries with developing industries for this species include Thailand (120 000 metric tonnes estimated production for 2003), Viet Nam and Indonesia (30 000 metric tonnes estimated for 2003 each), with Taiwan Province of China, the Philippines, Malaysia and India together producing several thousand tonnes.

Total production of *P. vannamei* in Asia was approximately 316 000 metric tonnes in 2002, and it has been estimated that this has increased to nearly 500 000 metric tonnes in 2003, which is worth approximately US$ 4 billion in terms of export income. However, not all the product is exported and a large local demand exists in some Asian countries.

The main reason behind the importation of *P. vannamei* to Asia has been the perceived poor performance, slow growth rate and disease susceptibility of the major indigenous cultured shrimp species, *P. chinensis* in China and *P. monodon* virtually everywhere else. Shrimp production in Asia has been characterized by serious viral pathogens causing significant losses to the culture industries of most Asian countries over the past decade and slowing down of growth in production. It was not until the late 1990s, spurred by the production of the imported *P. vannamei*, that Asian (and therefore world) production levels have

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[1] In 1997, the majority of cultured Penaeid shrimp were renamed according to the book "Penaeid and Sergestid shrimps and Prawns of the World" by Dr. Isabel Perez Farfante and Dr. Brian Kensley. Most scientists and journal editors have adopted these changes. Whilst the names *Litopenaeus vannamei* and *L. stylirostris* are technically now considered correct, the majority of the readers of this report will probably be more familiar with the original name *Penaeus vannamei* and *Penaeus stylirostris*. For the purposes of this report, therefore, the genus name *Penaeus* will still be used throughout.

[2] Throughout this document one billion is equal to one thousand million.

begun to rapidly increase again. By comparison, *P. vannamei* production has greatly reduced in Latin America also as a result of disease problems, however, there has so far been little sign of recovery.

In Asia, first Yellow Head Virus (YHV) from 1992 and later White Spot Syndrome Virus (WSSV) from 1994 caused continuing direct losses of approximately US$ 1 billion per year to the native cultured shrimp industry. In Latin America, first Taura Syndrome Virus (TSV) from 1993 and later, particularly, WSSV from 1999 caused direct losses of approximately US$ 0.5 billion per year after WSSV. Ancillary losses involving supporting sectors of the industry, jobs, and market and bank confidence put the final loss much higher.

It is widely believed that these three most economically significant viral pathogens (and a host of other pathogens) have been introduced to the Asian and Latin American countries suffering these losses through the careless introduction of live shrimp stocks. Most Asian countries have legislated against the introduction of *P. vannamei* due to fears over the possibility of introducing new pathogenic viruses and other diseases from Latin America to Asia. Many governments have allowed importation of supposedly disease free stocks that are available for this species from the USA.

The encouraging trial results, the industry-perceived benefits, including superior disease resistance, growth rate and other advantages, allied with problems in controlling the imports from other countries, have led to the widespread introduction of this species to Asia, primarily by commercial farmers. Unfortunately, importation of cheaper, non-disease free stock has resulted in the introduction of serious viral pathogens (particularly TSV) into a number of Asian countries, including Mainland China, Taiwan Province of China, Thailand and Indonesia, and maybe more.

Although TSV is not reported to have affected indigenous cultured or wild shrimp populations, insufficient time and research have been conducted on this issue and there is a need for caution. TSV is a highly mutable virus, capable of mutating into more virulent strains, which are able to infect other species. In addition, other viruses probably imported with *P. vannamei*, for example a new LOVV-like virus, have been implicated in actually causing the slow growth problems currently being encountered with the culture of the indigenous *P. monodon*. There remain many unanswered questions regarding the possible effects of introduced species and associated pathogens on other cultured and wild shrimp populations in Asia.

For such reasons there has been caution on the part of many Asian governments. However, this caution has not been demonstrated by the private sector, which has been bringing stocks of illegal and often disease carrying *P. vannamei* into Asia from many locations, as well as moving infected stocks within Asia. The commercial success of these introductions, despite disease problems, has allowed the development of substantial culture industries for these alien Penaeids within Asia and in China and Thailand in particular. One effect of this is that it is rapidly becoming difficult to control the importation and development of this new industry.

Despite the problems with disease transfer, *P. vannamei* (and *P. stylirostris*) does offer a number of advantages over *P. monodon* for the Asian shrimp farmer. These are largely associated with the ability to close the life cycle and produce broodstock within the culture ponds. This relieves the necessity of returning to the wild for stocks of broodstock or postlarvae (PL) and permits domestication and genetic selection for favourable traits such as growth rate, disease resistance and rapid maturation. Through these means, domesticated stocks of SPF and specific pathogen resistant (SPR) shrimp have been developed and are currently commercially available from the USA.

Other specific advantages include rapid growth rate, tolerance of high stocking density, tolerance of low salinities and temperatures, lower protein requirements (and therefore production costs), certain disease resistance (if SPR stocks are used), and high survival during larval rearing. However, there are also disadvantages, including their acting as a carrier of various viral pathogens new to Asia, a lack of knowledge of culture techniques (particularly for broodstock development) in Asia, smaller final size and hence lower market price than *P. monodon*, need for high technology for intensive ponds, competition with Latin America for markets, and a lack of support for farmers due to their often illegal status. Informed decisions regarding these pros and cons need to be taken, with close cooperation between governments, the private sector and NGOs to decide on the best course of action to take. Unfortunately, due to the rapid rise of *P. vannamei*, there has been little time for such considered actions concerning shrimp imports and movements.

The recent publication of a number of codes of conduct and management guidelines (BMPs) for the transboundary importation of alien shrimp and their subsequent culture by, amongst others, FAO, the OIE, NACA, ASEAN, SEAFDEC and the GAA have clearly defined most of the issues involved. With the availability of SPF and SPF/SPR stocks of *P. vannamei* and *P. stylirostris* from the Americas, Asia has had the opportunity to decide whether to responsibly undertake such importations for the betterment of their shrimp culture industries and national economies, whilst avoiding the potential problems with viral diseases and biodiversity issues. However, a number of factors are described to have prevented this ideal situation from manifesting. Although many of the potential problems related to transboundary movements of shrimp and their viral passengers are as yet unknown, it is important that Asian governments take action in legislating control over this industry.

Examples of countries that have managed to legislate for and enforce codes of conduct and management practices (as outlined in this report), and develop successful industries for the culture of imported *P. vannamei*, include the USA (and especially Hawaii), Venezuela and Brazil. These countries have succeeded despite early failures and disease episodes, demonstrating that such measures can and do work if rigorously applied.

This report has attempted to gather all of the currently available data on the extent of *P. vannamei* and *P. stylirostris* importation and culture in Asia, its potential problems and benefits, and in this way serve as a source document from which to investigate further the means by which control over this issue might be re-established.

Recommendations aimed at controlling the importation, testing and culture of these species have been made for all levels and are included in this report.

2. Background

In 2002, global aquaculture production reached 39.8 million metric tonnes with a value of US$ 53.8 thousand million. This represented an increase in production of 5.3 percent by weight and 0.7 percent by value over the previous year. Although cultured crustaceans represented only 5.4 percent of total production by weight, they comprised 20.1 percent of total global aquaculture by value in 2002. Despite being affected by serious disease outbreaks in both Latin America and Asia, the annual rate of growth of the cultured shrimp sector grew by 6.8 percent (by weight) between 1999 and 2000. Although this had dropped to 0.9 percent during 2002, these growth rates are still high relative to other food producing sectors. The global shrimp production has decreased to more modest levels over the last decade (averaging 5 percent) relative to the double-digit growth rates which were observed during the 1970's (23 percent) and 1980's (25 percent) (FAO Fishstat database[3], 2003).

Modern shrimp farming began in the late 1960s and early 1970s, when French researchers in Tahiti developed techniques for intensive breeding and rearing of various Penaeid shrimp species including *Penaeus japonicus*, *P. monodon* and later *P. vannamei* and *P. stylirostris*. At the same time, in China, *P. chinensis* were produced in semi-intensive ponds, while *P. monodon* were produced in small intensive ponds in Taiwan Province of China. Also, in North America, the Department of Commerce's National Marine Fishery Service (NMFS) began funding research into shrimp farming.

Early Penaeid culture efforts in the Americas during this period concentrated on indigenous species including *P. setiferus* in Panama, *P. aztecus* and *P. occidentalis* in Honduras and *P. aztecus* and *P. duorarum* in southern USA, *P. schmitti* and *P. brasiliensis* in Brazil, and then *P. stylirostris* in Panama. However, initial work with *P. vannamei* in 1972 gave much better production than the other species. When Brazilian authorities initially banned the import of *P. vannamei*, culture was started in Panama in 1974. Although *P. stylirostris* was producing well in Panama, and eyestalk ablation led to easy spawning, year round production was impossible. The better results obtained with *P. vannamei* encouraged work on maturation and spawning of wild broodstock. Once nutritional requirements of the broodstock were met, eyestalk ablation techniques led to successful all year reproduction of *P. vannamei,* and it replaced *P. stylirostris* in Panamanian commercial production in 1978 (Rosenberry, 2001).

By the mid-1970s, fisherfolk and hatcheries were supplying large numbers of postlarvae (PL) shrimp and global cultured shrimp production started to increase rapidly reaching 22 600 metric tonnes in 1975. At this time, Ecuadorian farms were starting to produce large numbers of *P. vannamei* through extensive culture. Mainland China and Taiwan Province of China were producing *P. chinensis* semi-intensively and Thailand's *P. monodon* industry was just starting. Over the next decade, production grew to 200 000 metric tonnes, 75 percent of which was from Southeast and Eastern Asia. By 1988, production increased rapidly exceeding 560 000 metric tonnes principally as a result of increased production from Mainland China, Taiwan Province of China, Ecuador, Indonesia, Thailand and the Philippines (Rosenberry, 2001).

The first major production crash occurred in Taiwan Province of China during 1987-89, when *P. monodon* production suddenly declined from 78 500 metric tonnes to 16 600 metric tonnes, widely considered to be due to pollution, stress and increased susceptibility to pathogens, especially viruses. Following this crash, Chinese technicians and culture techniques spread around the world, particularly to Thailand, which saw the rapid development of many small intensive farms for *P. monodon* and which became the world's leading shrimp producer starting in 1993, a position it held until the year 2000.

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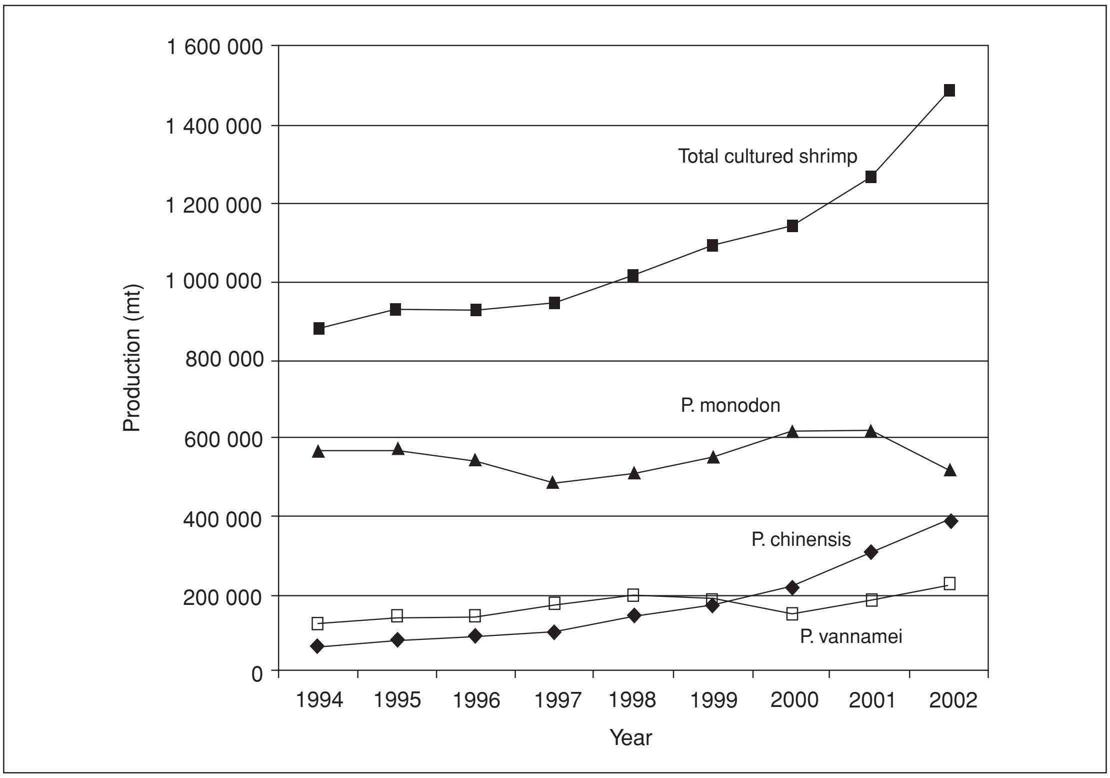
[3] http://www.fao.org/fi/statist/statist.asp

In 1989, the first major crash in price for farm-raised shrimp occurred, when the farm gate prices for Asian shrimp fell from US$ 8.50 to US$ 4.50/kg. This was largely due to the extended illness and subsequent death of Japan's emperor Hirohito, which stopped shrimp consumption in Japan, which was the world's largest market at the time. This price decrease may also have been due to the oversupply



Source: FAO Fishstat (2003)

Figure 1: World production of cultured shrimp species (1994-2001)

of shrimp on the world's markets, which had grown by 25 percent over the fairly static 2 million metric tonnes level sustained for years from fishery, due to the increasing production from shrimp farms.

Further crashes in production have subsequently characterized the world's shrimp farming industry, largely viral disease-related. These occurred first in Mainland China, when production fell from 207 000 metric tonnes in 1992 to 64 000 metric tonnes in 1993-1994 due to White Spot Syndrome Virus (WSSV) outbreak. Similar continuing problems in Thailand, the Philippines and Indonesia, first with Yellow Head Virus (YHV) and then WSSV, have occurred since the early 1990s. A similar scenario has also been seen in Ecuador and the rest of Central America owing to bacterial and then viral disease problems, first with Taura Syndrome Virus (TSV) in the mid-1990s and then WSSV from 1999 onwards.

In Asia, during the early 1990s, Viet Nam, India and Bangladesh also developed sizeable industries with *P. monodon*. In Latin America, Honduras, Mexico and Colombia developed large semi-intensive industries based on *P. vannamei* and *P. stylirostris*. Through the early to mid-1990s, production hovered around 700 000-900 000 metric tonnes as some countries experienced severe production downturns, due largely to YHV and WSSV in Asia and TSV in Latin America, whilst others developed their industries (Table 1). Subsequently, production has risen again, largely due to increased competence in the management of viral problems with *P. monodon* in Asia, and the closing of the life cycle and development of domesticated and genetically selected lines of *P. vannamei* in Latin America, and particularly now, with the increasing culture of *P. vannamei* in Asia.

Table 1: World production and value of cultured shrimp species (1994-2001)

Year	Total shrimp and prawns			*Penaeus monodon*				*Penaeus chinensis*				*Penaeus vannamei*			
	Quantity (mt)	Value US$ million	Value (US$/kg)	Quantity (mt)	Value US$ million	Value (US$/kg)	% of total	Quantity (mt)	Value US$ million	Value (US$/kg)	% of total	Quantity (mt)	Value US$ million	Value (US$/kg)	% of total
1994	881 959	5 809	6.59	599 363	3 896	6.50	68	64 389	519	8.06	7	120 585	736	6.11	14
1995	928 239	6 063	6.54	566 451	3 491	6.16	61	78 820	595	7.55	8	141 739	861	6.07	15
1996	920 870	6 118	6.68	539 606	3 873	7.18	58	89 228	629	7.05	10	140 180	865	6.17	15
1997	936 992	6 108	6.52	482 639	3 571	7.40	51	104 456	743	7.12	11	172 609	943	5.46	18
1998	1 004 541	6 058	6.23	505 168	3 226	6.74	50	143 932	996	6.92	14	197 567	1 081	5.47	19
1999	1 069 855	6 636	6.32	549 515	3 818	7.21	50	171 972	1 126	6.55	16	186 573	1 033	5.54	17
2000	1 143 774	7 402	6.73	618 178	4 507	7.70	54	219 152	1 325	6.05	19	146 095	911	6.23	13
2001	1 280 457	7 932	6.63	615 167	4 277	7.67	48	306 263	1 851	6.04	24	184 353	1 133	6.15	15

Source: FAO Fishstat (2003)

Globally, marine shrimp continue to dominate crustacean aquaculture, with three major species accounting for over 75 percent of total shrimp aquaculture production in 2002 (the giant tiger prawn, *P. monodon;* the fleshy prawn, *P. chinensis;* and the whiteleg shrimp, *P. vannamei*) (Figure 1). The giant tiger prawn only ranked 16th in terms of global aquaculture production by weight in 2002, but it ranked second in terms of value at US$ 3 371 thousand million (second only to the massive production of freshwater silver carp).

World cultured shrimp production levels reached 1.48 million metric tonnes by 2002 (accounting for more than 49 percent of global capture and cultured shrimp production) (FAO, 2002; Chamberlain, 2003) (Table 1 and Figure 1). The contribution of *P. monodon* has remained stable at around 600 000 metric tonnes from 1994 through 2002, whilst its contribution to world shrimp production has declined from over 63 percent to 40 percent in 2002, as *P. chinensis* and now particularly *P. vannamei* productions have increased to more than 500 000 metric tonnes between them (FAO, 2002). Current estimates compiled for this report suggest that the rapid growth of *P. vannamei* culture in Asia, particularly in Mainland China and Thailand, may result in a production of nearly 500 000 metric tonnes of Asian *P. vannamei* in 2003 (Table 3).

Projections estimate that the world's shrimp culture industry will continue to grow at 12-15 percent/year, although prices in the US market have been steadily decreasing by 4 percent/year from US$ 10 to US$ 8/kg since 1997 (National Marine Fisheries Service website[4]) (Figure 1). In 2003, first quarter figures showed record imports into the US market, with fairly stable prices, although consumer confidence and the US and Japanese national economies remain low. Additionally, the increasing oversupply of *P. vannamei* from first Mainland China and soon other Asian countries, as well as Brazil and other South and Central American countries, will probably lead to a continuation in declining prices. This is compounded by the slow growth rate (9 percent/year since 1996) of the world's largest shrimp market, the USA (importing 430 000 metric tonnes in 2002), the slow European market (300 000 metric tonnes in 2002) and the declining Japanese market (250 000 metric tonnes in 2002) (Chamberlain, 2003; Globefish website[5]; NMFS website) (Tables 8 & 9 and Figure 3). Costs have also increased as the industry adjusts to increasing international standards on product quality and the environment, putting huge pressures on the majority of the world's shrimp producers. In Thailand, declining prices and uncertainty over market access have led a signficant number of farms to shift back to the culture of the indigenous Penaeid, *P. monodon* in 2004.

[4] http://www.nmfs.noaa.gov/(US Department of Commerce)

[5] http://www.globefish.org/

3. History of introductions of Penaeid shrimp

The use of alien[6] animal species to increase food production and income has a long history and has been an established practice since the middle of the 19th century. Controversy over the use of alien species arises from the many highly publicized and spectacular successes and failures. The FAO database of introduced aquatic species[7] (DIAS) reports that aquaculture development has been the primary reason cited for most introductions, accounting for 40 percent of all cases. It also indicates that the number of introductions (65 percent being intentional) has increased exponentially since 1940. Most of these introductions are of fish, with only 6 percent or 191 records being of crustaceans. Such movements have been facilitated by recent advances in transport, which have made large-scale movements of many species increasingly easy. They are also directly related to the rapid global development of aquaculture and the demand for new species to culture (DIAS; Fegan *et al.*, 2001).

3.1 Natural range of *Penaeus vannamei* and *Penaeus stylirostris*

Penaeus vannamei is native to the Pacific coast of Mexico and Central and South America as far south as Peru, in areas where water temperatures are normally over 20ºC throughout the year (Wyban and Sweeny, 1991; Rosenberry, 2002). It is not currently known whether there is one population or if isolated populations exist, although there appear to be differences between stocks from various areas under culture conditions.

Penaeus stylirostris is native to the Pacific coast of Central and South America from Mexico to Peru, occupying the same range as *P. vannamei*, but with higher abundance, except in Nicaragua at the peak of the range of *P. vannamei* (Rosenberry, 2002). It has recently been demonstrated that there are at least six morphologically and genetically distinct populations of *P. stylirostris* in the Gulf of California, Mexico alone (Lightner *et al.*, 2002), raising the probability that there will be variations in their suitability for aquaculture.

3.2 Early movements for experimental culture

The first experimental movements of Penaeid shrimp began in the early 1970s when French researchers in Tahiti developed techniques for intensive breeding and rearing of various alien Penaeid species including *P. japonicus*, *P. monodon* and later *P. vannamei* and *P. stylirostris*.

In the late 1970s and 1980s, *P. vannamei* and *P. stylirostris* were transferred from their natural range on the Pacific coast of Latin America from Mexico to Peru. From here, they were introduced to the North-western Pacific coast of the Americas in the USA and Hawaii, and to the Eastern Atlantic coast from Carolina and Texas in the north through Mexico, Belize, Nicaragua, Colombia, Venezuela and on to Brazil in the south. Most of these countries now have established aquaculture of these species. *Penaeus monodon* and *P. japonicus* were also introduced in the 1980s and 1990s from Asia to various Latin American countries and the USA, including Hawaii, (where SPF populations have been established), and Ecuador and Brazil, where introductions were not successful.

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6 An alien species as defined by the Convention on Biological Diversity (Rio de Janeiro, 2002) is i) a species that has been transported by human activities, intentional or accidental, into a region where it does not naturally occur (also known as an exotic, introduced, non-indigenous, or non-native species) or ii) a species occurring in an area outside of its historically known natural range as a result of intentional or accidental dispersal by human activities (also known as an exotic or introduced species)(UNEP, 1995).

7 http://www.fao.org/fi/statist/fisoft/dias/index.htm

Introductions of *P. vannamei* to Asia began in 1978/79, when it was introduced to the Philippines (FAO correspondent), and in 1988 to Mainland China (FAO correspondent). Of these first trials, only Mainland China maintained production and started an industry. In 1988, a batch of *P. vannamei* PL were introduced into Mainland China from the Marine Science Institute of Texas University. By 1994, the Chinese aquaculturists were producing their own PL, and commercial shrimp culture began in the late 1990s. A similar early introduction of less than 100 000 PL *P. vannamei* into the Philippines in 1987 from "Agromarina" in Panama was not successful (Fred Yap, per. com.) and culture of this species was suspended for another ten years (Table 2).

SPF *P. stylirostris* have also been experimentally introduced to many Asian countries (including Brunei, Taiwan Province of China, Myanmar, Indonesia and Singapore) from secure breeding facilities in Mexico and the USA. These introductions began in 2000, but have yet to make a major impact on the culture industries in those countries (with the exception of a small industry in Brunei), but without notable problems so far. *Penaeus stylirostris* was also introduced into Thailand and Mainland China in 2000, but has yet to make much impact in these countries.

3.3 Movement for commercial production

The introductions of *P. vannamei* to non-native areas of the Americas, the Pacific and lately to Asia, have had a significant positive effect on the production capacities of the countries involved. This is probably the first time that this has ever been recorded with cultured shrimp. However, potential negative impacts are already being reported and will be discussed further in this report.

Brazil

Due largely to an inability to breed and rear local shrimp species intensively (especially under high temperatures and low dissolved oxygen conditions), Brazil first imported *P. japonicus* in 1980, *P. monodon* in 1981 and *P. vannamei* and *P. stylirostris* in 1983, followed by *P. penicillatus* in 1994 (Roberto Andreatta *et al.*, 2002; de Barros Guerrelhas, 2003). Commercial production of *P. vannamei* began in 1983, but it was not until 1995 that this species became predominant. This was due largely to the importation of highly productive Panamanian stocks (in 1991), the mastering of its captive maturation, fast growth, efficient food conversion and high survival rates obtainable in ponds and its good market potential in Europe and the USA.

USA

Penaeus vannamei was first imported to the USA as postlarvae from Panama in 1985 into South Carolina, USA. It has steadily risen in popularity to become the main species of shrimp farmed in North America (Sandifer *et al.*, 1988). *Penaeus monodon* were also imported into South Carolina from Hawaii in 1988 and subsequently escaped and have since been captured along the Eastern Atlantic coast down to Florida, although it is still not considered to be established (McCann *et al.*, 1996).

Six species of Penaeid shrimp (*P. vannamei*, *P. monodon*, *P. stylirostris*, *P. japonicus*, *P. chinensis* and *P. indicus*) have been introduced into Hawaii for culture and research purposes. Only *P. vannamei* is currently under commercial pond culture, although there still remain stocks of most species (except *P. indicus* which failed to clear pathogen screening and was destroyed), which are used for generation of SPF and SPR stocks for sale to other countries (Wyban, per. com.; Eldridge, 1995; Hennig *et al.*, 2003). Most of the original stocks were brought into Hawaii between 1978 and 1985, and imports have subsequently slowed due to fears over the importation of alien viruses (Eldridge, 1995). Brock (1992) provides a list of the known shrimp viruses which were already present in Hawaii in 1992. Although individuals of *P. vannamei*, *P. monodon*, *P. stylirostris* and *P. japonicus* have escaped culture, none is known to be locally established (Brock, 1992; Eldridge, 1995).

Table 2: Importation of *P. vannamei* and *P. stylirostris* in Asian countries and the Pacific

Country	First introduction of *P. vannamei*	Original source	Original cultured species	Reason for importing *P. vannamei*	First introduction of *P. stylirostris*	Source of brood/PL imports	Current ban on imports	Current viral diseases
Mainland China	1988	Tx	C, M, J, P, Me	Diversification, performance	1999	Tx, Ti, Hi	No	WSSV, YHV, TSV, SMV, HPV, IHHNV, BP, MBV, BMNV, HB, LOPV, REO-III
Taiwan Province of China	1995	Hi	M, J, Ma	Problems w. *P. monodon*	2000	Hi, Ch	No	WSSV, YHV, IHHNV, MBV, TSV
Thailand	1998	Ti	M, Me, J	Problems w. *P. monodon*	Yes	Hi, Mx, Ch, Ti	September, 2002	WSSV, MBV, BMNV, HPV, YHV, IHHNV, LOVV, TSV, MOV
Viet Nam	2000	Ch	M	Prob. w. *P. monodon,* cold tolerance	No	Ti, Ch, Hi	Except for 9 licensees	WSSV, YHV
Philippines	1997	Ti	M, I, Me	Problems w. *P. monodon*	No	P, Ti	1993, 2001	WSSV, YHV
Indonesia	2001	Hi	M, Me	Problems w. *P. monodon*	2000	Ti, Hi	Restricted to license holders	WSSV, YHV, MBV, TSV, IHHNV
Malaysia	2001	Ti	M, S	Problems w. *P. monodon*	No	Ti, Th	June, 2003	WSSV, MBV, BMNV, HPV, YHV, IHHNV
India	2001	Ti	M, I, Ma	Problems w. *P. monodon*	No	Ti, Hi	Except for a few trials	WSSV, MBV, HPV, YHV
Sri Lanka	None	N/A	M	N/A	No	N/A	Guidelines in force	WSSV, YHV, MBV
Pacific Islands	1972	Mx, P	M, Me, J	Experiments, cold tolerance	1972	Mx, P, Hi	Fiji has Regulations	None

Notes: **Cultured species:** C = *P. chinensis*, M = *P. monodon*, Me = *P. merguiensis*, I = *P. indicus*, S = *P. stylirostris*, J = *P. japonicus*, P = *P. penicillatus*, Ma = *Macrobrachium rosenbergii*
Source/Broodstock Imports: Hi = Hawaii, Ti = Taiwan Province of China, Ch = Mainland China, Mx = Mexico, Th = Thailand, Tx = Texas, P = Panama

Pacific Islands

Although there are approximately 20 indigenous species of Penaeid shrimp amongst the islands of the South Pacific and Hawaii, nine alien species have been introduced, initially into Tahiti and New Caledonia, since 1972. These include *P. monodon*, *P. merguiensis*, *P. stylirostris* and *P. vannamei* (since 1972, Table 2), *Metapenaeus ensis, P. aztecus*, *P. japonicus* and *P. semisulcatus* (since 1973) and *P. indicus* (in 1981) (Eldridge, 1995). In addition, *P. stylirostris* were introduced into French Polynesia (from Mexico and Panama) in 1978, into Fiji (from Hawaii) in the mid-1990s and *P. vannamei* were introduced to Fiji (from Hawaii) in 2002 (Ben Ponia, per. com.) (Table 2).

Of all these species, only one, *P. merguiensis* has so far become established in Fiji. Despite release into the wild, *P. japonicus* has not become established (Eldridge, 1995). Despite all the research efforts stretching back over 30 years, shrimp farming is still a very small industry in the Pacific Islands, with a total production of 2 272 metric tonnes in 2002, mostly of *P. stylirostris* from New Caledonia (Ben Ponia, per. com.). Constraints include limited domestic markets, transportation costs and social, economic and climatic problems (Adams *et al.*, 2001).

Asia

The first commercial shipment of SPF *P. vannamei* broodstock from the Americas to Asia was from Hawaii to Taiwan Province of China in 1996 (Wyban, 2002) (Table 2). Initial successes with the maturation, larval rearing and culture of this species in Taiwan Province of China led to a huge demand for broodstock and to the first introductions of wild broodstock from many sources in Latin America in 1997. Initial production of 12 metric tonnes/ha of 12-15 g shrimp in 75 days were reported (Wyban, 2002), similar to current production levels in Thailand and Indonesia.

By mid-1998, farmers in both Mainland China and Taiwan Province of China were producing their own pond-reared broodstock. In early 1999, TSV, imported with wild broodstock from Latin America, began to cause significant (80 percent in three days) mortality of juvenile shrimp in ponds in Taiwan Province of China (Tu *et al.*, 1999; Yu and Song, 2000). In addition, WSSV was also causing mortalities, and runt deformity syndrome (RDS) and slow growth due to Infectious Hypodermal and Haematopoietic Necrosis Virus (IHHNV) was common. These disease problems led to decreased profits and the tendency to use cheaper pond-reared broodstock, without consideration of genetic makeup or biosecurity. This led to inbreeding and increased introduction of disease through hatchery produced PL. Despite these problems, the production of *P. vannamei* in Taiwan Province of China (7 633 metric tonnes) in 2002 was higher than that of *P. monodon* (1 828 metric tonnes).

After Taiwan Province of China, Mainland China began importing SPF broodstock of *P. vannamei* from Hawaii in 1998 (Wyban, 2002) to augment their own production of pond-reared broodstock. Similar early successes led to huge imports of broodstock, both SPF from Hawaii and non-SPF[8] from Taiwan Province of China, throughout 1999. The latter (and possibly their own cultured broodstock) led to similar disease problems with TSV as in Taiwan Province of China in 2000. Despite these difficulties and drawbacks, the immense human and physical resources (and demand) in Mainland China led to their emergence as the world's leading producer of shrimp, in particular *P. vannamei,* during this decade (Wyban, 2002). Production levels in Mainland China of *P. vannamei* were approximately 270 000 metric tonnes in 2002, and they are expected to rise to 300 000 metric tonnes in 2003 (more than the rest of the world combined). This amount is 71 percent of China's total expected shrimp production of 415 000 metric tonnes in 2003 (Table 3).

[8] Non-SPF refers to individuals bred in captivity but not under high biosecure conditions and not using SPF protocols.

Table 3: Production of all shrimp and *P. vannamei* in some Asian countries and the Pacific

Country/Region	Total shrimp Production (mt/yr)		*P. vannamei* Production (mt/yr)		*P. vannamei* Percentage of total	
	2002	Est. 2003	2002	2003	2002	Est. 2003
Mainland China	415 000	420 000	272 980	300 000	66	71
Taiwan Province of China	18 378	19 000	7 667	8 000	42	42
Thailand	260 000	300 000	10 000	120 000	4	40
Viet Nam	180 000	205 000	10 000	30 000	6	15
Philippines	36 000	38 000	3 425	5 000	10	13
Indonesia			5 000	20 000	10	23
Malaysia	23 200	27 000	1 200	3 600	5	13
India	145 000	150 000	350	1 000	0	1
Sri Lanka	3 368	3 400	0	0	0	0
Pacific Islands	10 931				0	0
Total	**1 091 877**	**1 162 400**	**310 622**	**487 600**	**27**	**38**

Note: Sources of this information are from country correspondents and these figures are not official. All data for 2003 are estimates made by the authors.

Subsequently, *P. vannamei*, both SPF and SPF/SPR (for TSV) from USA, and non-SPF from Latin America and Taiwan Province of China/Mainland China have been introduced into many Asian countries including the Philippines (1997), Thailand (1998), Indonesia and Viet Nam (2000), Malaysia and India (2001) and Myanmar and Bangladesh, in some cases without official approval (Fegan, 2002; Taw *et al.*, 2002; Wyban, 2002) (Table 2).

During the last three years, due primarily to the advantages of culturing *P. vannamei* and problems with the growth rate of *P. monodon* (which was the preferred species prior to that time), *P. vannamei* has gained prominence across Asia and production has increased significantly until 2003, particularly in Mainland China and Thailand. In 2004 this rate of increase slowed markedly and even declining as many farmers faced low farm gate prices and uncertain market access as a result of the anti-dumping case in the USA, which is one of the major importing markets.

Although difficult to estimate (due to the privacy of information of the commercial companies involved), with five to six commercial SPF broodstock suppliers in Hawaii and one in Florida, the USA's SPF *P. vannamei* broodstock industry is currently worth some US$ 5 000 000/year, the vast majority of which is now being exported to Asia. This equates to a figure of some 28 000 broodstock (14 000 females) per month, translating into a possible six billion nauplius and three billion PL/month. This number is sufficient for stocking 4 000 ha/month, itself capable of producing 24 000 metric tonnes/month, or 288 000 metric tonnes/year from the USA SPF *P. vannamei* broodstock alone.

Penaeus stylirostris is the major shrimp species cultured in Mexico, but has been replaced or out-competed by *P. vannamei* in every other country in the Americas. The SPF *P. stylirostris* have been promoted to many Asian countries during the past three years, but this species has only had a significant impact in Brunei, which has quadrupled its production since the importation of SPF *P. stylirostris* in 2000. Other trials in Taiwan Province of China, Myanmar, Indonesia and Singapore have been less successful and have not yet led to commercial culture operations in these countries/region (Table 2). Thailand and Mainland China also imported non-SPF *P. stylirostris* in 2000, but they have yet to make an impact on the shrimp production of either country.

4. Advantages and disadvantages of *P. vannamei* and *P. stylirostris*

There are many reasons for the introduction of *P. vannamei* and *P. stylirostris* into areas where they are not indigenous. Despite the presence of various international, regional and country-specific regulations (Section 7), the private sector (and/or the state sector) will often attempt to initiate introductions due to problems that they face with the culture of their indigenous species and the perceived (rightly or wrongly) production benefits of the alien species. There may also exist marketing advantages and a desire to expand, intensify and/or diversify aquacultural practices. The improved transportation efficiency available recently has also removed some old limitations and encouraged international movement of alien species.

The advantages and disadvantages of *P. vannamei* and *P. stylirostris* as compared to native species, specifically *P. monodon,* are shown in Table 4. Data on the productivity of *P. vannamei* compared to *P. monodon* are shown in Table 5.

The reasons behind the introductions of these alien species and the possible risks involved are described below:

4.1 Growth rate

Penaeus vannamei has the potential to grow as fast as *P. monodon* (at up to 3 g/wk) up to 20 g (the maximum size of *P. vannamei* usually cultured) under intensive culture conditions (up to 150/m^2). Although it will keep growing beyond 20 g, its growth may slow (particularly males) to 1 g/wk once above 20 g in weight (Wyban and Sweeny, 1991).

Under commercial conditions in Asian earthen ponds, however, typical growth rates of 1.0-1.5 g/wk (with 80-90 percent survival) are common in the high density pond system (60-150/m^2) currently in use in Thailand and Indonesia. In contrast, the growth (and survival) rate of *P. monodon* has been declining in recent years from 1.2 to 1 g/wk (and 55 percent to 45 percent survival) over the last five years in Thailand (Chamberlain, 2003) due perhaps to disease load and/or genetic inbreeding (Table 5). *Penaeus stylirostris* can also grow equally fast and to a larger size than *P. vannamei*.

4.2 Stocking density

Penaeus vannamei are amenable to culture at very high stocking densities of up to 150/m^2 in pond culture, and even as high as 400/m^2 in controlled recirculated tank culture. Although such intensive culture systems require a much higher degree of control over environmental parameters, it enables the production of high numbers of shrimp in limited areas, resulting in better productivity per unit area than that currently achievable with *P. monodon* in Asia.

Both *P. monodon* and *P. stylirostris* can be aggressive, have high protein requirements, and may be more demanding of high water quality, making them difficult to culture as intensively as *P. vannamei*.

4.3 Salinity tolerance

Penaeus vannamei tolerates a wide range of salinities, from 0.5-45 ppt, is comfortable at 7-34 ppt, but grows particularly well at low salinities of around 10-15 ppt (where the environment and the blood are isosmotic) (Wyban and Sweeny, 1991). This ability makes it a good candidate for the newer inland farms that have become common in Asia and Latin America in the past few years. For example, a high percentage of Chinese *P. vannamei* are cultured in inland, freshwater sites, where production is much higher than with the indigenous species.

Table 4: Summary of advantages and disadvantages of the culture of *P. vannamei* and *P. stylirostris* over *P. monodon* in Asia

Characteristic	Advantages	Disadvantages
Growth rate	*P. vannamei* and *P. stylirostris* can grow as fast as *P. monodon* up to 20 g and typically grows faster (1-1.5 g/wk) than *P. monodon* (1 g/wk) currently in Asia. Size range on harvest generally smaller.	Growth rate of *P. vannamei* slows after reaching 20 g, making production of large-sized shrimp slower.
Stocking density	*P. vannamei* is easier to culture in very high densities (typically 60-150/m^2, but up to 400/m^2) than *P. monodon* and *P. stylirostris* which can be aggressive.	Very high stocking densities require high control over pond/tank management practices and are high-risk strategies.
Salinity tolerance	*P. vannamei* are tolerant of a wide range of salinities (0.5-45 ppt) and more amenable to inland culture sites than *P. monodon* or *P. stylirostris.*	None
Temperature tolerance	*P. vannamei* and particularly *P. stylirostris* are very tolerant of low temperatures (down to 15^{o}C) enabling them to be cultured in the cold season.	None
Dietary protein requirements	*P. vannamei* require lower protein feed (20-35%) than *P. monodon* or *P. stylirostris* (36-42%), resulting in a reduction in operational costs and amenability for closed, heterotrophic systems. Food Conversion Ratios (FCRs) are lower at 1.2 compared to 1.6.	None
Disease resistance	Although *P. vannamei* is susceptible to WSSV, Asia is not currently experiencing problems from this virus; *P. stylirostris* is highly resistant to TSV. Both species have been selected for resistance to various diseases. Survival rates with *P. vannamei* are thus currently higher than with *P. monodon* in Asia and production is more predictable.	*P. vannamei* is highly susceptible to and a carrier of TSV, WSSV, YHV, IHHNV and LOVV. *P. monodon* is refractory to TSV and IHHNV. There is currently no ability to select *P. monodon* for disease resistance.

Table 4: Summary of advantages and disadvantages of the culture of *P. vannamei* and *P. stylirostris* over *P. monodon* in Asia *(continued)*

Characteristic	Advantages	Disadvantages
Ease of breeding and domestication	Availability of pond-reared broodstock; ability to conduct domestication and genetic selection work; SPF and SPR lines already available; elimination of problems associated with wild broodstock and/or PL collection; source of cheap broodstock from ponds; and small sized broodstock mean faster generation times.	SPF animals sometimes have high mortality in disease-laden environments. Broodstock rearing and spawning more technical and complicated than use of wild *P. monodon* spawners.
Larval Rearing	Higher survival rates in hatchery of 50-60% for *P. vannamei* and *P. stylirostris* compared to *P. monodon* (20-30%).	None
Post-harvest characteristics	If treated with ice, *P. vannamei* are resistant to melanosis.	Handling, transportation and processing of *P. monodon is* easier.
Marketing	White shrimp generally preferred in US market over tiger shrimp due to taste. Strong local demand for white shrimp in Asia. Meat yield is higher for *P. vannamei* (66-68%) than for *P. monodon* (62%)	*P. monodon* and *P. stylirostris* can grow to larger size, commanding higher price than *P. vannamei.* High competition on international markets for *P. vannamei* as production is world-wide.
Origin	None	*P. vannamei* and *P. stylirostris* are alien to Asia and their importation may cause problems with import of new viruses and contamination of local shrimp stocks.
Government support	None	No support from most countries since they remain undecided on ban imports and farming of *P. vannamei.* Supply of broodstock and seed problematic in face of bans, leading to smuggling of sub-optimal stocks and disease introduction.

Table 5: Production, survival and cost data for *P. vannamei* and *P. monodon* in Asian countries and the Pacific

Country/Region	Total production area (ha)	*P. vannamei* production area (ha)	*P. vannamei* production (mt/ha/cycle)	*P. vannamei* survival (%)	*P. monodon* production (mt/ha/cycle)	*P. monodon* survival (%)	*P. vannamei* production cost (US$/kg)	*P. monodon* production cost (US$/kg)
China	246 275	68 837	7 to 11	?	<7.5	?	2.00	2.00
Thailand	80 000	32 000	6 to 7	80	3	45	2.14	3.10
Viet Nam	479 000	48 000	4 to 7	80	4 to 5	?	?	?
Philippines	158 920	700	4	90	5 to 8	80	1.89	3.40
Indonesia	350 000	1 000	3 to 5	65	1 to 3	?	?	?
Taiwan Province of China	8 160	3 053	?	?	?	?	1.95	3.50
Malaysia	7 260	200	5 to 12	85	1.5 to 9	45	2.63	4.27
India	186 710	120	4	85	0.4	65	3.35	3.50
Sri Lanka	1 300	0	N/A	N/A	?	?	N/A	4.13
Pacific Islands	500	0	N/A	N/A	?	?	N/A	?
Total	**1 518 125**	**153 910**	**Average 4 to 7**	**Average 85**	**Average 3 to 5**	**Average 60**	**Average 2.33**	**Average 3.41**

Note: All data is for 2002

This trend is likely to continue due to concerns over coastal development including biosecurity, land cost and conflicts with other users of common resources in coastal zones. In addition, farmers in Thailand have been prohibited from farming *P. monodon* in freshwater areas, whilst no such restrictions currently apply to *P. vannamei*. *Penaeus stylirostris* and *P. indicus* are not as able to tolerate low salinities, so are less suitable for this purpose.

4.4 Temperature tolerance

Although *P. vannamei* will tolerate a wide range of temperatures, it grows best between 23-30ºC (comprising the majority of the tropical and subtropical world), with the optimum for growth being 30ºC for small (1 g) and 27ºC for larger (12-18 g) shrimp. They will also tolerate temperatures down to 15ºC and up to 33ºC without problems, but at reduced growth rates (Wyban and Sweeny, 1991). *Penaeus vannamei* (and *P. stylirostris*) can thus be profitably cultured during the cool season in Asia (October-February). This is traditionally the low season for *P. monodon* farmers in this part of the world, meaning that increased yearly harvests may be possible using these alien species. This greater temperature tolerance of *P.* vannamei may also be a reason why farmers have perceived this species to be more resistant to WSSV relative to *P. monodon.* However, recent experience in Thailand, Ecuador and elsewhere has shown that when water temperatures decline to less than 30ºC, increased problems with viral diseases such as WSSV and TSV occur not just with *P. monodon*, but equally with *P. vannamei*.

Penaeus stylirostris can tolerate even colder temperatures than *P. vannamei*, *P. monodon* or *P. indicus* but require higher oxygen levels (Rosenberry, 2002).

4.5 Dietary protein requirement

Compared with other species, *P. vannamei* requires a lower protein (and hence cheaper) diet (20-35 percent) during culture than *P. monodon*, *P. chinensis* or *P. stylirostris* (36-42 percent), and are more able to utilize the natural productivity of shrimp ponds, even under intensive culture conditions (Wyban and Sweeny, 1991). In Thailand for example, current grow-out feeds for *P. vannamei* contain 35 percent protein and cost 10-15 percent less than the 40-42 percent protein feeds for *P. monodon*. Additionally, feeding efficiency is better with *P. vannamei*, which yield an average FCR of 1.2, compared to 1.6 for *P. monodon* (Dato Mohamed Shariff, per. com.). These factors, together with higher growth and survival rates are responsible for the 25-30 percent lower production costs for producing 20 g of *P. vannamei* than *P. monodon* (US$ 2.33 compared to US$ 3.41/kg across Asia, Table 5).

Recent commercial results from Indonesia have shown that *P. vannamei* growth, survival and production rates all slightly increased using 30-32 percent compared to 38-40 percent protein diets in intensive ($60/m^2$) culture (Taw *et al.*, 2002). Additionally, results from recycled, heterotrophic systems originating from Belize and now also being used in Mainland China, Indonesia and elsewhere have shown that even lower protein levels of 20 percent or less can be used successfully with *P. vannamei* if the natural bacterial productivity of the ponds is correctly stimulated (McIntosh *et al.*, 1999).

4.6 Ease of breeding and domestication

Both *P. vannamei* and *P. stylirostris* are open thelycum species, meaning that they can be induced to mate and spawn easily in captivity (unlike the closed thelycum *P. monodon*) which enables the culturist to close the life cycle of the shrimp, facilitating genetic selection (i.e. for improved growth rate and disease resistance) and domestication programmes. This feature permits much more control and enhancement of the cultured stock and allows the development of SPF and SPR stocks, which are already commercially available. This in turn relieves the expense, disease implications, environmental concerns, unpredictability and waste of relying on wild broodstock.

Table 6. Hatchery and PL production for all shrimp and *P. vannamei* in Asian countries and the Pacific

Country/Region	*P. vannamei* maturations	*P. vannamei* hatcheries	Other Shrimp hatcheries	Total shrimp PL production (million PL/mo)	*P. vannamei* PL production (million PL/mo)
China	?	1 959	1 893	56 375	9 900
Taiwan Province of China	20	150	250	754	644
Thailand	20	26	2 000	3 700	1 200
Viet Nam	9	9	4 800	1 600	90
Philippines	0	0	250	200	0
Indonesia	?	15	300	?	?
Malaysia	5	10	95	200	50
India	0	3	293	600	2
Sri Lanka	0	0	80	22	0
Pacific Islands	0	0	9	101	0
Total	**54**	**2 172**	**9 970**	**63 552**	**11 886**

Note: All data are unofficial figures, based on industry estimates for 2002.

Despite the ease of obtaining pond-reared broodstock and subsequently spawning them, these techniques are by no means simple. Many Asian farmers have no experience with these techniques, which is leading to difficulties with seed production in Thailand, Indonesia, Malaysia and other countries. This, in turn, results in farmers importing PL and broodstock of often unknown health status into the country for stocking their ponds. This practice is a major risk for bringing viral and other pathogens into once-clean areas. These risks could be reduced through approved and well designed and run SPF-maturation and broodstock centres in each country wanting to culture these new species.

The extent of maturation and larval culture facilities in Asia is shown in Table 6. Apart from Mainland China and Taiwan Province of China, which have relatively well-established industries for *P. vannamei*, the other countries in Asia have very few maturation and larval culture facilities for this species. More facilities can be expected, once these other nations perfect their broodstock production and hatchery techniques for *P. vannamei* and the demand for PL grows.

This ability to produce high-quality, fecund domesticated stocks can also be seen as an advance in the sustainability and environmental friendliness of shrimp farming since it precludes the necessity of catching large numbers of wild post-larvae and wild broodstock (and the wastage associated with the by-catch from these activities). Production of pond-reared broodstock is also much cheaper than buying wild-caught animals from fisherfolk and is also economically advantageous.

Work on the domestication of *P. monodon* has been going on for some time in the USA, Australia and Thailand, but as yet without commercial success. However, it is expected that, from 2004, for the first time, SPF domesticated broodstock of *P. monodon* have been made commercially available from Hawaii (Wyban, per. com.) and also probably from Thailand within the next couple of years. Thailand's National Science and Technology Development Agency (NSTDA), together with the National Centre for Genetic Engineering and Biotechnology (BIOTEC), have continued their previous work with *P. monodon* domestication with a US$ 4 million government grant and have already developed sixth generation animals SPF for WSSV and YHV. If successful, this development will allow the same degree of control over the life cycle of *P. monodon* as is currently available for *P. vannamei* and *P. stylirostris*.

However, minimum spawning size for *P. monodon* females is 100 g, which will take at least 10-12 months under commercial pond conditions, whilst *P. vannamei* and (less so) *P. stylirostris* can be spawned at only 35 g, which can be achieved easily in 7 months. This has obvious advantages over *P. monodon* in terms of generation times and the expense involved in producing captive broodstock.

4.7 Larval rearing

Larval survival rates during hatchery rearing are generally higher (50-60 percent) with *P. vannamei* and *P. stylirostris* than with *P. monodon* (20-30 percent) (Rosenberry, 2002).

4.8 Disease resistance

Penaeus vannamei is generally considered to be more disease resistant than other white shrimp (Wyban and Sweeny, 1991), although it is in fact highly susceptible to WSSV and TSV (can cause high mortality) and a carrier of IHHNV (results in runt deformity syndrome – RDS) and Lymphoid Organ Vacuolization Virus (LOVV). Mostly owing to its perceived disease tolerance, it is replacing the less virus-tolerant *P. chinensis* in southern Mainland China (Rosenberry, 2002). Nonetheless, uninformed farmers throughout Asia recently began farming *P. vannamei* in the belief that it was resistant to WSSV and YHV, encouraged by traders and salespeople involved in this business.

To date, Thailand, Malaysia and Indonesia have not suffered major WSSV or YHV-related epidemics with *P. vannamei*, despite the presence of these pathogens in the environment. This has translated into current survival rates of 80-90 percent with *P. vannamei* on some farms, compared to just 45-60 percent with *P. monodon* (Table 5). The disease resistant view of *P. vannamei* is no longer held by many farmers in Mainland China, Taiwan Province of China and Thailand, where disease epidemics within *P. vannamei* farms have started, but are typically blamed on TSV.

Injection of WSSV into *P. vannamei* and *P. stylirostris* was shown to result in 100 percent mortality within 2-4 days, proving its infectivity and pathogenicity was similar to that found with *P. monodon*, *P. japonicus* and *P. chinensis* (*P. orientalis*) (Tapay *et al.*, 1997). The WSSV has also been identified as the prime cause of major mortalities of *P. vannamei* and *P. stylirostris* in Latin America since 1999. However, some unpublished work has suggested that WSSV alone may have only 30 percent of the effect of a mixture of viruses on mortality of *P. vannamei* fed infected shrimp tissue in Ecuador (Matthew Briggs and Neil Gervais, per. com.). Additionally, the generally higher water temperatures experienced in tropical Asian countries may help to limit mortalities due to WSSV in *P. vannamei* (compared to Latin America) since WSSV has been shown repeatedly to lose its virulence in water over 30ºC in temperature.

Penaeus monodon is generally regarded as being highly susceptible to both WSSV and YHV, but not to IHHNV or TSV, although *Macrobrachium rosenbergii*, another important cultured prawn in Southeast Asia, is sensitive to TSV (Rosenberry, 2002; Flegel, 2003). *Penaeus stylirostris* from the wild are highly susceptible to the IHHN virus, leading to their falling out of favour with Latin American farmers in the late 1980's. However, the ability to domesticate and selectively breed for disease resistance confers a big advantage on *P. vannamei* and *P. stylirostris* until domesticated lines of *P. monodon* become available. Domesticated lines of both *P. vannamei* and *P. stylirostris* have been shown to gain resistance to both IHHN and TSV. *Penaeus stylirostris* have been injected with TSV and were not found to get infected, so are refractory, rather than resistant (Timothy Flegel, per. com.). This trait has promoted a resurgence in the farming of *P. stylirostris* in Mexico and interest in *P. vannamei* culture in Asia where the lack of domesticated *P. monodon* precludes the possibility of selection for disease resistance (Rosenberry, 2002).

Penaeus monodon are highly resistant to IHHNV, but do act as carriers, so farmers must be careful to avoid cultivating *P. monodon* together with *P. vannamei* in maturation, hatchery or grow-out facilities, as cross contamination of viruses may result (Timothy Flegel, per. com.).

It is believed that the current declines in growth rate and survival of cultured *P. monodon* in Asia are due to the stress of high IHHN viral loading in the broodstock and the passing of these viruses to their offspring. Due to the coincidence in dates, it is even possible that these problems with *P. monodon* resulted from the introduction of viral pathogens carried by *P. vannamei*. A recently (December 2002, by Lightner) discovered Ribonucleic Acid (RNA) viral pathogen, very similar to LOVV in *P. vannamei,* has been detected in Thailand in the lymphoid organ of *P. monodon*. This new type of LOVV (temporarily named LOVV2) might be the causative agent of this slow growth phenomenon (see Section 6.3). This slow-growth problem was estimated to have resulted in US$ 5-10 million in lost earnings in 2002 (Timothy Flegel, per. com.). Additionally, recent research in Thailand has shown that even apparently healthy shrimp in culture ponds have a high prevalence of one to four different viral pathogens (Flegel, 2003).

4.9 Specific Pathogen Free (SPF) shrimp

One of the main advantages of culturing the shrimp species *P. vannamei* and *P. stylirostris* is that both species are commercially available as high health animals from SPF stocks. *Penaeus monodon* have very limited availability from SPF stocks, but this may well change in the near future as such stocks are currently under development (see Section 4.6). Nevertheless, at this time, the availability of domesticated strains of SPF *P. vannamei* and *P. stylirostris* offer great advantages over *P. monodon* and other native Asian shrimp, which must still be collected from the wild.

The status of Specific Pathogen Free should signify that the shrimp have passed through a rigorous quarantine and disease screening process that determined them to be free from specified pathogens of concern to culturists. This characteristic means that countries or regions which still do not have this species can be reasonably sure that the importation of SPF animals will not result in the introduction of the specified pathogens for which the animal is declared ‘free’. This does not, however, guarantee against the animal being infected with unknown pathogens or known pathogens which are not screened against.

There is significant confusion in Asia regarding the exact meaning of SPF. For example, a widely held belief is that SPF animals are resistant to and cannot become infected by any viral pathogens that they encounter during cultivation. This is most certainly not the case. SPF means that the animals have been assured of being free from specific pathogens. Whether a particular animal or strain is genetically resistant to a specific pathogen is independent of its present status. SPF refers only to the present pathogen status for specific pathogens and not to pathogen resistance or future pathogen status (Lotz, 1997).

Genuine SPF shrimp are those which are produced from biosecure facilities, have been repeatedly examined and found free of specified pathogens using intensive surveillance protocols, and originate from broodstock developed with strict founder population development protocols. These founder populations are generated by extensive quarantine procedures that result in SPF F1 generations derived from wild parents (Lotz, 1997). Only when raised and held under these conditions can you have true SPF stocks. There is not yet an internationally agreed protocol for the development of SPF shrimp and certainly some variation in the quality of different SPF stocks exists. Once the animals are removed from the SPF production facilities, they should no longer be referred to as SPF, even though they may remain pathogen free. Once outside the SPF facility, the shrimp may be designated as High Health (HH) as they are now subject to a greater risk of infection, but only if they are placed into a well-established facility with history of disease surveillance and biosecurity protocols. If the shrimp are put anywhere else, for example into a non-biosecure maturation unit, hatchery or farm, they can no longer be called SPF or HH as they are now exposed to a high risk of infection.

The primary goal of SPF facilities is to produce strains of shrimp that are disease-free, domesticated and genetically improved for aquaculture. Since, for *P. vannamei* and *P. stylirostris*, such SPF lines are available, it makes sense to use them to begin breeding programmes in those countries which are introducing these species for the first time. This is because even if the SPF lines are not resistant to major pathogens, they are not infected with them. Additionally, they are already domesticated and possess growth and behavioural characteristics that make them preferable to their wild counterparts. It is important to note here that the health aspect of a proposed introduction is only one part of the full risk assessment that should be undertaken prior to introduction. Other important aspects are the issue of whether the imported alien species is likely to be invasive and the likely impacts of escapees on wild populations and the environment.

Recent research work by some state and private companies has focused efforts on the development of SPF strains that are also resistant to specific pathogens (SPF/SPR). This is a long process, and usually focused on one pathogen at a time. Thus, although the development of pathogen resistant strains is a long-term goal of SPF breeding programmes, it is unlikely that they will ever result in strains that are unaffected by all disease organisms (Lotz, 1997).

One potential drawback of SPF animals is that they are only SPF for the specific diseases for which they have been checked. Typically this will consist of the viral pathogens which are known to cause major losses to the shrimp culture industry, including WSSV, YHV, TSV, IHHNV, BPV and HPV as well as microsporidians, haplosporidians, gregarines, nematodes and cestodes. Despite this screening, new, hidden or "cryptic" viruses may be present, but because they are as yet unrecognized, may escape detection. Thus, it is believed that SPF shrimp shipped from Hawaii resulted in the contamination of shrimp in Brazil and Colombia with TSV (Brock *et al.*, 1997). This was because, at the time, TSV was not known to have a viral cause and therefore went unchecked in SPF protocols.

Additionally, new diseases may emerge from mutations of previously non-pathogenic organisms – i.e. the highly mutable RNA viruses. Hence, it remains a possibility that importation of SPF shrimp may not rule out simultaneous importation of pathogens. Another possibility is that if SPF shrimp are stocked into facilities with high viral loads, substantial mortality can result as they are not necessarily more resistant to these diseases than non-SPF shrimp, and in some cases, less so. They may thus be more suited to culture in biosecure systems, which may explain the reliance of the big, non-biosecure pond farms of Latin America on SPR, rather than SPF shrimp.

In any case, the use of SPF stocks is only one part of a complete plan for minimizing disease risks in shrimp culture. The development of SPF strains is really designed to help ensure that PL stocked into grow-out ponds are free of disease, one of, if not the most serious source of contamination. Other areas of this strategy that must be implemented include: strategies to ensure broodstock, eggs, nauplius, larvae and juveniles derived from SPF stock remain SPF such as: farm biosecurity, early warning surveillance and rapid response to disease outbreaks. Recommended management strategies for maintaining biosecurity and disease surveillance are given in Annexes 2 and 3.

In response to disease problems due largely to IHHNV (the causative agent of runt deformity syndrome (RDS) in the USA in the late 1980s), a programme to develop SPF *P. vannamei* was started in 1989 in the United States Department of Agriculture (USDA)-funded Oceanic Institute in Hawaii (Wyban and Sweeny, 1991). This programme continues to this day and has been expanded by a number of commercial ventures, mostly located in Hawaii.

This initial work with SPF *P. vannamei* has been extended in the private sector to include work with *P. stylirostris*, *P. monodon*, *P. japonicus* and *P. chinensis* (principally in Hawaii but also in Florida and Mexico), *P. indicus*, *P. merguiensis* and *P. semisulcatus* (in Iran) and SPF stocks of *P. vannamei* with resistance to TSV (in the USA). Some of these lines are now more than ten generations SPF. Current suppliers of SPF (and SPR) strains of shrimp are shown in Table 7. Despite the declaration of SPR status, it is important to note that this resistance is only to some specific strains of TSV, not all of them, and even this is subject to proper confirmation[9].

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[9] To date, SPR status is only confirmed for a line of P. stylirostris resistant to IHHNV. There are some P. vannamei stocks with limited resistance to TSV strain 1, but this does not extend to strains 2 and 3. *There are **no** stocks available that are resistant to WSSV*.

Once outside an SPF facility, maintenance of High Health (HH) status requires that all SPF shrimp must be quarantined, isolated and reared away from those that may be infected for their entire life cycle to prevent the spread of pathogens to the clean stock. Once the initial SPF stock has been established, new HH stock can be produced locally, using specific rearing techniques that avoid contamination. These techniques, although known, are not easy to fulfil and so far have only been achieved in the USA (and possibly Iran).

Another point to consider when buying SPF stocks with which to begin domestication programmes in other countries, is that such stocks may have been deliberately in-bred and consist entirely of siblings. This means that future generations of animals based only on such lines will probably lead to inbreeding within a few generations. Such inbreeding has been noted in stocks of *P. stylirostris* bred in Tahiti for 22 generations (Bierne *et al.*, 2000). It has also been noted in captive stocks of *P. vannamei*, which were characterized by a diminished ability to tolerate TSV challenges compared to a more diverse, heterozygous wild control population (Jones and Lai, 2003).

There are many problems involved with the use of non-SPF broodstock. The first and foremost has already been discussed which is the possibility of importing novel pathogenic viruses and other diseases into new or clean areas. This has already been seen in Asia with the introduction of *P. vannamei* into Mainland China, Taiwan Province of China and Thailand. The problem here is that non-SPF shrimp tend to be cheaper and more easily available (pond-reared broodstock in Asia currently sell for US$ 8-10, whilst SPF broodstock from Hawaii cost US$ 23-25 delivered) and are hence initially attractive, but may have long-term negative consequences.

In addition, without strict biosecurity and disinfection protocols for treating non-SPF broodstock, eggs and nauplius (which are largely unknown and unused in Asia), any pathogens infecting the broodstock tend to be passed to the larvae which increases the possibility of serious disease problems during on-growing. Another problem is that it is extremely difficult to ascertain whether the stocks bought in are really SPF or not. Often competent testing facilities do not exist in Asian countries and many unscrupulous dealers will sell supposedly SPF stocks with false certificates to unwary farmers. A final problem is that whilst SPF stocks are almost certainly domesticated lines which have been selected for growth and disease resistance over a long period, non-SPF stocks may not have been selected and are of often uncertain parentage. This makes their use as founder populations for genetic selection and domestication programmes undesirable.

4.10 Specific Pathogen Resistant (SPR) shrimp

SPR is another term that is often misconstrued and is short for Specific Pathogen Resistant. It describes a genetic trait of a shrimp that confers some resistance against one specific pathogen. SPR shrimp usually result from a specific breeding programme designed to increase resistance to a particular virus. SPF and SPR are independent characteristics. Not all SPR shrimp are SPF and vice versa.

Much work has been done on the selective breeding of *P. vannamei* and *P. stylirostris* for increased growth rate and resistance to a variety of diseases, with many positive results. Such work was initiated in Tahiti by "Aquacop" in the early 1970s with a variety of species, and by the Oceanic Institute and commercial companies using their original SPF lines since 1995.

In fact, recent research work by some state and private companies has focused efforts on the development of SPF strains that are also resistant to specific pathogens (SPF/SPR). These strains are typically resistant to only one pathogen, currently largely either TSV or IHHNV, but some work has indicated that strains with multiple resistance to TSV and WSSV (at up to 25 percent survival to challenge tests) may be possible (Jim Wyban, per. com.). This is accomplished by challenging sub-lots of shrimp families to a particular pathogen (or combination of pathogens) and then selecting the most resistant families as broodstock for the next generation. Some recent work with SPF/SPR strains of *P. vannamei* challenged

Table 7: Suppliers of SPF and SPR shrimp

Facility	Location	Species	Stage	SPF	SPR
High Health Aquaculture Inc.	Hawaii	M, V, S, J	B, N, PL	Yes	To TSV1
Shrimp Improvement Systems	Florida	V	B, N, PL	Yes	To TSV1
Molokai Sea Farms Intl.	Hawaii	V	B, N, PL	Yes	To TSV1
The Oceanic Institute	Hawaii	V	B, N, PL	Yes	To TSV1
Ceatech USA Inc.	Hawaii	V	B, N, PL	Yes	To TSV1
Kona Bay White Shrimp	Hawaii	V	B, N, PL	Yes	No
AFTM	Iran	I, Me, Se	B, N, PL	Yes	?
Xiamen Xinrongteng ATD	China	V, J	PL	No	?
Unknown	China	V	B	No	No
Seajoy S.A.	Ecuador, Honduras	V	B, N, PL	No	?
Pacific Larval Centre, Inc.	Panama	V	B, N, PL	No	?
Aquaculture de La Paz S.A.	Mexico	V	B, N, PL	No	?
Tincorp S.A.	Ecuador	V	B, N, PL	No	?
C.I. AquaGen S.A.	Colombia	V	PL	No	?
Supershrimp Group	California	S	B, N, PL	Yes	To IHHN
Farallon Aquaculture S.A.	Panama	V	PL	Yes	To TSV1

Source: First author

Notes: **SPF/SPR status**: 'Yes' indicates the claims of the supplier, however, detailed information is not available to the authors regarding the actual pathogens that the stock supplied is claimed to be free of, or resistant to.

Specific pathogen resistance to TSV is only for certain TSV strains, not all. To date, SPR status is only confirmed for *P. stylirostris* strain resistant to IHHNV. Some *P. vannamei* stocks exist with limited resistance to TSV strain 1 but not to strains 2 and 3. There are *no* stocks available that are resistant to WSSV.

Species: M = *P. monodon*, V = *P. vannamei*, S = *P. stylirostris*, J = *P. japonicus*, I = *P. indicus*, Me = *P. merguiensis*, Se = *P. semisulcatus*

Life stage: B = Broodstock, N = Nauplius, PL = Postlarvae

with different isolates of TSV has shown survival rates of 55-100 percent in the lab and 82 percent in ponds (Jim Wyban, per. com.; James Sweeney, per. com.).

A selective breeding programme for *P. vannamei* was initiated in 1995 in the Oceanic Institute in Hawaii. Original work was based on a selection index weighted equally for growth and TSV resistance (the major disease problem in the Americas at that time). Confirmation that growth and survival (to TSV challenge) responded well to selection was obtained, but there appeared to be a negative genetic correlation between these traits. Further investigation revealed that the shrimp selected only for growth were 21 percent larger than unselected shrimp (24 vs. 20 g) after one generation, with a realized heritability (h2) of 1. Females were 12.7 percent larger than males at about 22 g, but it was not possible to select for a higher percentage of females. Meanwhile, shrimp selected on an index weighted 70 percent for TSV resistance and 30 percent for growth showed an 18 percent increase in survival to a TSV challenge (46 vs. 39 percent) after one generation, with a realized heritability (h2) of 0.28. However, selected shrimp were 5 percent smaller than control shrimp, revealing a negative genetic correlation between mean family growth and mean family survival to a TSV challenge. This negative correlation between growth and disease resistance must therefore be taken into account when developing breeding plans for these shrimp (Argue *et al.*, 2002).

However, recent work in progress in a US-based facility producing SPF and SPR *P. vannamei* has reportedly achieved a growth rate potential of 2 g/week with families of shrimp selected for resistance to TSV, with no negative correlation between growth and survival. Additionally, they have seen an 18 percent/generation average improvement in growth rate in families selected only for growth (Edward Scurra, per. com.).

SPR strains of shrimp, however, do not necessarily have to be SPF. Latin America is now almost exclusively using pond-grown and (often) disease checked and quarantined SPR *P. vannamei* due to their better performance in maturation, hatcheries and grow-out ponds. A recent survey conducted by FAO revealed that there were close to 100 maturation units (mostly in Ecuador and Mexico), producing 15 billion nauplius/month, stocking close to 400 hatcheries, mostly of SPR *P. vannamei* (and *P. stylirostris* in Mexico) (FAO, 2003).

The Latin American SPR strains of *P. vannamei* have high genetic diversity, coming from multiple sources (both SPF and non-SPF), and have been selected from the survivors of multiple disease outbreaks in grow-out ponds, in some cases for five years or more (i.e. in Panama, Ecuador, Colombia and Brazil). They may thus have more resistance to a combination of diseases (*i.e.* WSSV, TSV and IHHNV) than their purely SPF counterparts and be uniquely adapted to the culture conditions and diseases encountered in their respective countries. Commercial results have indicated that such selection procedures can enhance both maturation attributes (*i.e.* behaviour, time to spawning and spawning rate) and growth rate (10 percent increase/generation) and survival (disease resistance) during pond on-growing (Matthew Briggs and Neil Gervais, per. com.).

TSV can cause significant losses in farms stocked with *P. vannamei* and can be transmitted easily through insect or avian vectors between ponds. Because of this, the use of TSV-resistant strains combined with biosecurity measures to reduce infections with other viruses such as WSSV, IHHNV and YHV could greatly assist the development of the new culture industry for *P. vannamei* in Asia. Such a protocol was adopted by the USA industry that, as a result, has seen 50 percent growth rate per year over the last three years (Wyban, 2002).

Some work has also recently been done developing a strain of *P. chinensis* that is SPR for WSSV. Improvement in survival rate from 0-0.8 percent to 12-45 percent was recorded from ponds stocked with PL produced from survivors of a WSSV epidemic, whilst lab challenge tests revealed 30-60 percent improvements in survival rates for 3rd and 4th generation survivors. That this was due to resistance was proven by polymerase chain reaction (PCR) testing which showed both control and selected animals to have an average 60 percent infection rate with WSSV (Jie *et al.*, 2003).

The development of WSSV-resistant lines of *P. vannamei* is a possibility. Because WSSV remains the biggest disease problem in Asian shrimp culture, this would provide a much-needed impetus for the Asian shrimp culture industry as a whole. The recent applications of quantitative genetics to shrimp breeding, including the identification of various molecular markers (particularly microsatellites) associated with disease resistance and growth, offer a method through which the selection of fast-growing, disease resistant strains might soon become much more efficient. It may also shed some light on invertebrate antiviral immunity, about which currently nothing is known. Such disease related markers have already been identified for IHHNV in *P. stylirostris* (Hizer *et al.*, 2002).

The selected line of *P. stylirostris*, commercially known as “supershrimp”, have been shown to be 100 percent resistant to an infectious strain of IHHNV fed to juveniles during laboratory challenge tests. The shrimp remained free of the disease over the 30 day trial period and so were really refractory rather than resistant since the virus did not replicate within the shrimp (Tang *et al.*, 2000).

4.11 Post-harvest characteristics

After harvest, if well treated with plenty of ice, *P. vannamei* are particularly resistant to melanosis and keep a good appearance three to four days after defrosting. However, *P. monodon* tend to have a longer shelf life and are easier to handle, transport and process than *P. vannamei*.

5. Shrimp trade, marketing and economics

5.1 Current and potential world shrimp production levels

Current world shrimp culture production levels are shown in Tables 1 and 3 and Figure 1 and are updated regularly at the FAO Fishstat database[10].

5.2 Marketing advantages

White shrimp, such as *P. vannamei* and *P. stylirostris,* are the preferred species for consumption for the world's largest shrimp market – the USA. Additionally, from the USA consumers' point of view, they can be mixed together and sold as western white shrimp (Rosenberry, 2002). USA consumers appear to prefer the taste of *P. vannamei* over *P. monodon* (Rosenberry, 2002), particularly from freshwater production (UF/IFAS, 2003).

There is also a strong demand for *P. vannamei* in the local markets of Mainland China and Taiwan Province of China (where 75 percent and 100 percent, respectively, of their production is sold locally) and Thailand (Peterson, 2002). However, many Asian countries have no experience with *P. vannamei* and *P. stylirostris* and processing plants are often reluctant to accept this species until they have found established markets for this product.

Another advantage is that *P. vannamei* have a higher meat yield at 66-68 percent than *P. monodon* at 62 percent.

The ability to close the life cycle of *P. vannamei* and *P. stylirostris*, as well as their ability to be reared in closed, low-salinity systems, might also be seen as a marketing advantage, particularly for the image-conscious European market, which is being consumer-led to search for more environmentally friendly products.

5.3 Market value and market competition of Asia and the Pacific with Latin America

USA shrimp market

The USA has been the major market for farmed shrimp over the past few years, and the market condition in the USA is now the predominant factor affecting international market prices. Shrimp is the number one seafood consumed in the USA, with per capita consumption increasing from 1.3 kg in 2000 to 1.6 kg in 2001. Imports have now reached 430 000 metric tonnes/year, worth US$ 3.4 thousand million, and are increasing at 7 percent/year (Tables 8 and 9 and Figure 3). Imported shrimp accounted for 88 percent of the demand, with local production only able to meet 12 percent of that demand (Globefish website[11], NMFS website[12]).

The USA market share between Latin America and Asia was 67 percent from Asia and 33 percent from Latin America in 2002 which is a significant increase for Asia in recent years (56 percent from Asia and 44 percent from Latin America in 1999) (Globefish website; NMFS website).

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[10] http://www.fao.org/fi/statist/statist.asp

[11] http://www.globefish.org/marketreports/Shrimp/Shrimp

[12] http://www.st.nmfs.gov/pls/webpls/trade

Despite problems with the USA economy, the market demand recovered somewhat in 2002 after a 40 percent decrease in retail prices following the September 2001 terrorist attack on New York, although in general prices have been declining steadily since 1997 (Figure 3). Early 2003 has shown slow demand due to continuing problems with the USA economy and war in the Middle East (Globefish website; NMFS website).

In the USA market, the major exporters in 2002 were Thailand, Mainland China, Viet Nam and India. Thailand lost some ground due to problems with the culture of *P. monodon*, whilst Mainland China increased dramatically due to the new production and export of *P. vannamei*. Other countries increasing their share included India, Ecuador and particularly Viet Nam and Brazil.

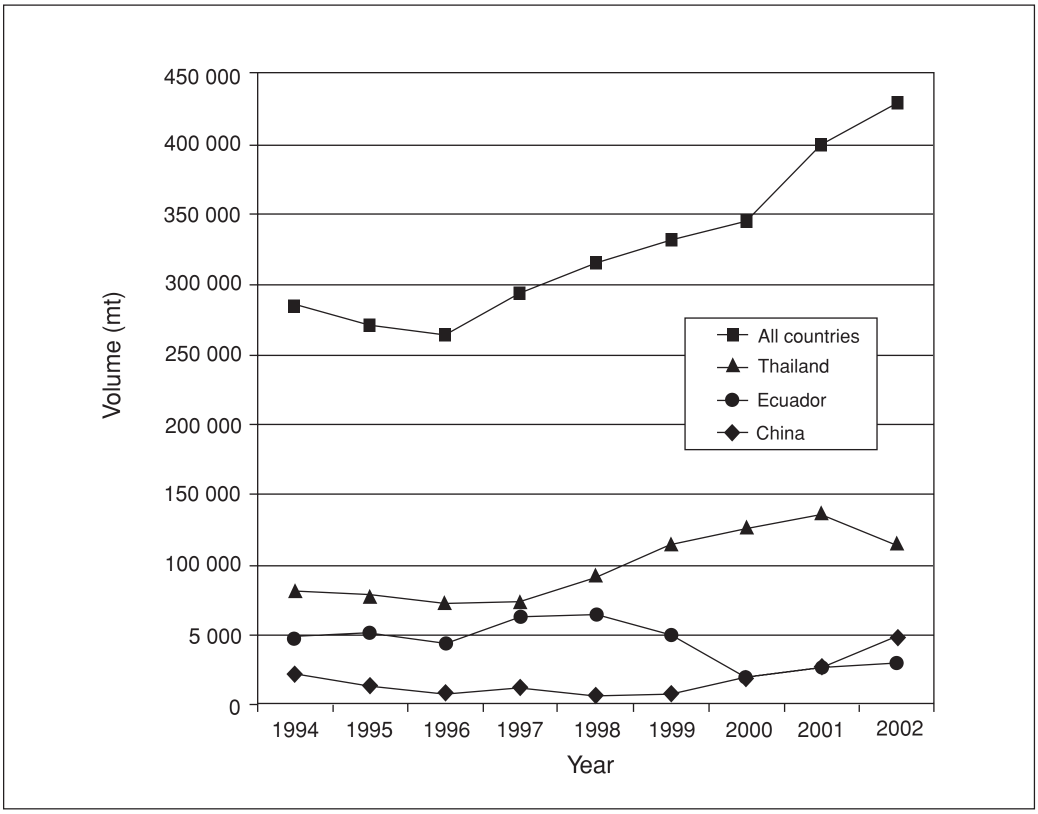
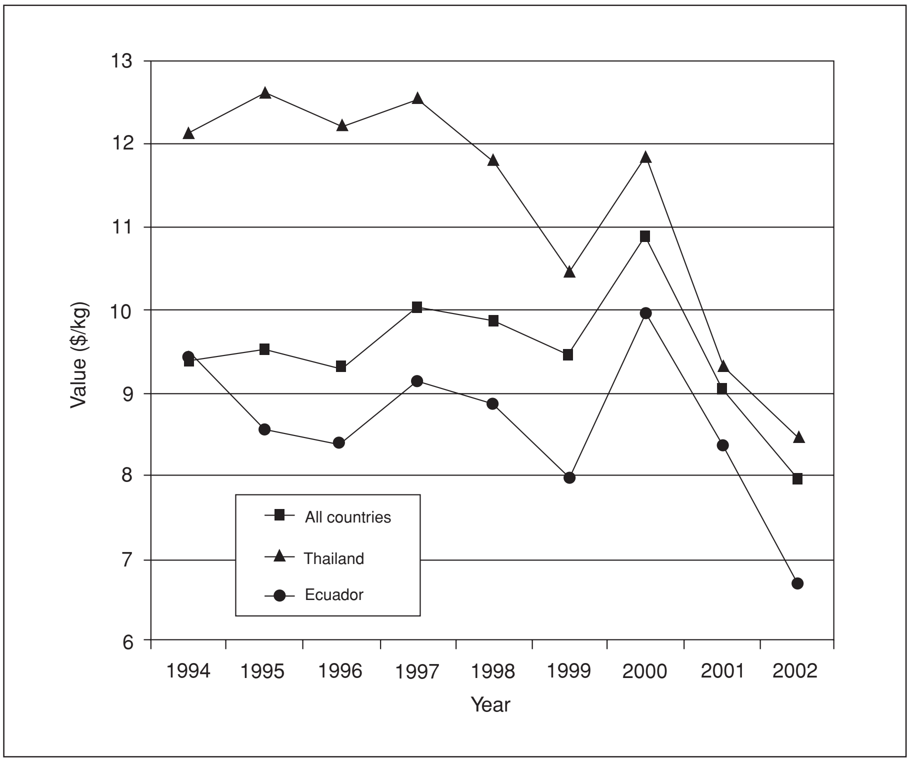


Figure 2: Importation of shrimp to the USA from all and selected countries (1994-2002)

Although Thailand lost some overall share, they increased exports of value added shrimp and are currently the major supplier of such shrimp to the United States market. Thailand exported 42 percent of its shrimp as processed product in 2001 and it is attempting to increase this towards 80 percent to increase diversity, value and maintain its lead in exports of processed shrimp. Thailand can expect to face greater competition in export markets from Mainland China, Viet Nam and India in the near future, however, as these countries continue to improve the quality of their processing industries (Globefish website; NMFS website; TFRC website[13]).

The huge importation of shrimp into the USA market, combined with falling prices, have recently led to accusations of dumping by the shrimp fisherfolk of the USA. In 2004, a group of fisherfolk and shrimp farmers (the Southern Shrimp Alliance) have brought an antidumping case to the US International Trade Commission (ITC) aimed at reducing the quantity of shrimp imported by the US and raising prices

[13] http://www.tfrc.co.th



Source: **NMFS website;** http://www.st.nmfs.gov/pls/webpls/trade

Figure 3: Average value (US$/kg) of shrimp imported into the USA (1994-2002)

(The Wave website, July, 2003[14]). This ongoing issue may result in the imposition of high tariffs on shrimp that are imported from the major producing countries in the world. For the Asian region (as of April 2004), this includes China, Viet Nam, Thailand and India. One of the effects of this type of action is that the market will seek to source shrimp from countries unaffected by the tariffs and there will inevitably be increased competition between the Asian exporters and greater uncertainty for producers. At the same time, there is renewed interest to revert to Black Tiger shrimp (*P. monodon*) production in order to access alternative markets. One of the possible positive aspects of this is that the increased awareness of the benefits of SPF/SPR shrimp may encourage renewed efforts to produce similar captive *P. monodon* broodstock. Currently, almost the entire *P. monodon* production industry is still based upon the capture of wild broodstock.

Another problem for most shrimp producers is the well publicised EU restrictions related to the detection of banned antibiotic residues in shrimp and the USA which has also introduced much stricter controls over testing for these banned antibiotics (chloramphenicol and nitrofurans). With the introduction of technology capable of detecting 0.1 ppb levels of these substances, the testing for and enforcement of these levels on future shrimp imports will inevitably lead to problems for exporting countries.

Introduction of stricter testing has been facilitated by the development of more sophisticated analytical equipment, driven partially by consumer concerns over food safety. Additional import controls relate to the antidumping case by USA shrimp fisherfolk and farmers, who claim that they are being put out of business through the importation of cheap farmed shrimp. A result of this is that product traceability from pond to plate is also becoming a greater priority.

[14] http://thewaveonline.com

Table 8: Importation of shrimp into the USA from all and selected countries (1994-2002)

Year	All countries Volume (mt)	All countries Value US$ million	All countries Value (US$/kg)	Thailand Volume (mt)	Thailand Value US$ million	Thailand Value (US$/kg)	Thailand % USA market	Ecuador Volume (mt)	Ecuador Value US$ million	Ecuador Value (US$/kg)	Ecuador % USA market	China Volume (mt)	China Value US$ million	China Value (US$/kg)	China % USA market
1994	284 828	2 668	9.37	80 789	981	12.14	28	48 107	455	9.46	17	22 854	105	4.59	8
1995	270 891	2 581	9.53	77 796	981	12.61	29	51 758	443	8.56	19	14 644	80	5.43	5
1996	264 207	2 457	9.30	72 716	888	12.21	28	44 087	370	8.39	17	7 746	35	4.57	3
1997	294 207	2 954	10.04	73 402	921	12.55	25	63 738	583	9.15	22	12 879	68	5.26	4
1998	315 442	3 112	9.87	92 265	1,088	11.79	29	64 548	572	8.86	20	6 996	36	5.13	2
1999	331 706	3 138	9.46	114 503	1,197	10.45	35	50 413	403	7.99	15	8 846	49	5.57	3
2000	345 077	3 757	10.89	126 448	1,498	11.85	37	19 097	190	9.95	6	18 203	137	7.50	5
2001	400 337	3 627	9.06	136 078	1,266	9.30	34	26 760	224	8.37	7	28 017	192	6.84	7
2002	429 303	3 422	7.97	115 105	976	8.48	27	29 715	199	6.70	7	49 507	298	6.01	12

Source: **NMFS website**

Table 9: Importation of shrimp into the USA and Japan in 2002

Imports into USA				
Country	Volume (mt)	Value US$ million	Value (US$/kg)	% of market
All countries	429 303	3 422	7.97	100
Thailand	115 105	976	8.48	27
China	49 507	298	6.01	12
Viet Nam	44 686	481	10.77	10
India	44 245	364	8.22	10
Ecuador	29 715	199	6.70	7
Mexico	24 297	264	10.87	6
Brazil	17 733	88	4.95	4
Indonesia	17 437	153	8.78	4
Others	86 578	599	6.92	20

Imports into Japan				
Country	Volume (mt)	Value US$ million	Value (US$/kg)	% of market
All countries	248 842	2 200	8.84	100
Indonesia	53 607	536	9.99	22
Viet Nam	41 516	335	8.08	17
India	34 794	301	8.66	14
China	19 598	138	7.04	8
Thailand	18 986	190	10.03	8
Canada	9 367	49	5.22	4
Russia	8 961	69	7.70	4
Argentina	8 833	60	6.74	4
Others	53 180	522	9.81	21

Source: **NMFS website**

Japanese market

The Japanese market took 80 percent of its shrimp imports from Asian countries (particularly Indonesia, Viet Nam and India) in 2002, compared to just 20 percent from Latin America. The rest of the world supplied shrimp derived mostly from capture fisheries from Russia, Greenland, Canada and Argentina, with very little from the domestic culture industries of Ecuador (1 700 metric tonnes) and Brazil (1 000 metric tonnes) (NMFS website) (Table 9).

European market

The European market has always been more particular than the USA or Japanese markets and, due to consumer pressure has recently become even more concerned about a range of issues. These include: sustainable and controlled farming, antibiotic regulation, ethical employment standards, traceability, genetically modified feed ingredients, fishmeal sustainability, animal welfare, genetics in shrimp breeding, dioxins, polychlorinated bi-phenyls (PCBs) heavy metals, agrochemicals and irradiation.

A combination of these concerns (but particularly antibiotic residues) has led to recent restrictions on importation of farmed shrimp from many Asian countries (due to detection of chloramphenicol and nitrofuran metabolites) and from Ecuador (due to metabisulphite residues). The zero tolerance policy regarding chloramphenicol and nitrofuran has been particularly highlighted since improved detection capability within Europe has enabled previously undetectable levels of these two antibiotics to be found. The absence of technology and capacity to detect at these levels of sensitivity within the exporting countries has also led to disputes regarding the application of the more sensitive techniques and claims that this represents a technical barrier to trade.

In general, as economies around the world have slowed during recent years, and production (largely of *P. vannamei*) is rising, demand and hence prices have inevitably been decreasing.

As Ecuadorian and Latin American production of shrimp declined from 1999 due to the introduction of WSSV from Asia, Asian countries, particularly Mainland China, Thailand and Viet Nam, took advantage and increased their production dramatically. Although USA imports are increasing slowly, these production increases (from 1 million metric tonnes in 1998 to 1.6 million metric tonnes in 2003) coincided with a cooling in demand from Japan and Europe; the decreasing Japanese market is due to its poor economic status.

In Europe, higher tariffs (and strict antibiotic testing) are limitations in accessing the market. For Thailand (in 1998) and soon after for Viet Nam (2003), the removal of preferential tariffs for the European market will result in advantages for India, Indonesia, Malaysia, Myanmar and other countries with more favourable rates. This would effectively reduce the market share for these production giants. Mainland China also represents a considerable export force in the market with its production of *P. vannamei*, but it too has had problems with the European market due to detection of banned antibiotic residues in its shrimp (as have Thailand, Viet Nam, Indonesia and India) and hence restrictions on imports.

5.4 Trade advantages and disadvantages with *P. vannamei* and *P. stylirostris*

The major markets have traditionally imported more cultured *P. monodon* than *P. vannamei* and *P. stylirostris*, primarily due to greater supply of the former. However, the USA market prefers white shrimp as consumers say it is sweeter. Moreover, *Penaeus vannamei* has a greater percentage of tail meat (at 66-68 percent) than *P. monodon* (at 62 percent). With the increasing importation of value-added products, *P. vannamei* can fill roles traditionally taken by *P. monodon* since there are no obvious differences between the two products after processing (TRFC website).

With the slow growth of major world shrimp markets in recent years, increasing emphasis will inevitably be placed on the domestic markets of the major shrimp producers. In Asia, now the fastest growing and biggest producer of *P. vannamei*, Mainland China and Taiwan Province of China already have high and established demands for white shrimp (75 and 100 percent of production consumed locally, respectively), since previous production of *P. chinensis* created a ready market. After initial hesitance, Thai shrimp processors are also willing to accept *P. vannamei*, for both domestic (primed for white shrimp by initial culture and capture of *P. merguiensis* and *P. indicus*) (20-30 percent in 2003) and export markets, primarily as processed product (70-80 percent of Thai production in 2003) (TRFC website).

The ability to grow *P. vannamei* in freshwater may also be an advantage in the USA market, based on results of a consumer acceptance test run by the UF/IFAS Food Science and Human Nutrition Department of the University of Florida. This study concluded that USA consumers preferred freshwater grown *P. vannamei* over those grown in brackish or salt water or harvested from the sea. This was due to better aroma, appearance, flavour and texture characteristics of freshwater grown shrimp. They stated that there was a strong consumer demand in the USA for a higher quality product than that currently available (UF/IFAS, 2003).

However, there are disadvantages to the culture of *P. vannamei* in that they do not normally grow as large as *P. monodon* and *P. stylirostris* and cannot access the lucrative market for larger sized shrimp which have a much higher price per kilo. In addition, when white shrimp production begins in Asian countries, processors are often reluctant to accept the product since they do not have marketing routes established. For example, Thai processors did not accept or paid very low prices for *P. vannamei* until they identified marketing channels for them. Similarly, Malaysia is still without processors for *P. vannamei* and must send the product to Singapore or Thailand for processing (Dato Mohamed Shariff, per. com.).

If the culture of *P. vannamei* continues to grow in Asia, world production of this species will overtake that of all other shrimp species and will soon surpass the current market size. The inevitable result will be that prices will fall and there will be immense competition between Asian and Latin American producers with greater requirement for cost-cutting and enhanced efficiency. All of this will also be against a background of the current anti-dumping case of the USA shrimp fisherfolk and farmers.

6. Threats and risks of introducing alien shrimp species

6.1 Procedures and precautions for introductions

It is now becoming apparent that many of the introductions and movements of aquatic animals have been responsible for the introduction, establishment and spread of aquatic animal pathogen species (parasites, viruses, bacteria and fungi) into new geographic areas and hosts. Once established in natural waters (and often aquaculture facilities) and hosts, such pathogens are almost impossible to eradicate.

In most cases, fishery managers and governments have not properly considered pathogen transfer when contemplating transboundary movements of aquatic animals, or have been slow to react to such introductions directly by the private sector either with or without approval. With proper planning, it may have been possible to avoid introduction of these pathogens and there now exist a number of international codes of practice and guidelines to assist this process. These include international efforts led by the International Council for the Exploration of the Sea (ICES), Cartagena Protocol of the Convention on Biological Diversity (CBD), the World Organisation for Animal Health (OIE) Sanitary and Phytosanitary Agreement of the World Trade Organization (WTO/SPS), and the FAO Code of Conduct for Responsible Fisheries (CCRF). In Asia, the latest initiative is the FAO/NACA Regional Technical Cooperation Programme (TCP/RAS/6714(A) and 9605(A)) "Assistance for the Responsible Movement of Live Aquatic Animals", which led to agreement on the "Asian Technical Guidelines on Health Management for the Responsible Movement of Live Aquatic Animals" (Global Aquaculture Alliance website[15]; FAO/NACA/OIE, 1998; Fegan *et al.*, 2001).

Despite the existence of these codes, protocols and guidelines, governments and particularly the private sectors in both Asia and Latin America continue to introduce new shrimp species with limited consideration of potential disease consequences. They have thus generally been caught unprepared by the recent epizootic outbreaks involved with shrimp transboundary movements. Additionally, their immediate responses have been largely ineffective in preventing or reducing disease losses which may exceed US$ one thousand million/year in direct production losses worldwide and considerably more in total.

Countries who have actively enforced live shrimp importation bans, with some success include:

- Brazil, Venezuela and Madagascar (which have so far managed to exclude WSSV and YHV);
- Hawaii and the continental USA, which have managed to eradicate WSSV from their culture industry until recently when a fresh outbreak of WSSV was reported to OIE;
- The Philippines, which managed to delay the onset of WSSV by four to five years (compared to the rest of Southeast Asia), but do have non-SPF *P. vannamei* despite a ban on *P. vannamei* imports; and
- Sri Lanka, which still not allowed even experimental importations of *P. vannamei*, for fear of TSV.

Direct, involuntary importation of new pathogens with their imported hosts has been shown to be even difficult to quantify, including transfer of new strains of established pathogens specific to the host, the potential for interbreeding with, and displacement of, native species, and unknown effects on the genetic diversity and ecology of native fauna. Each of these has the potential to cause unexpected and far-ranging adverse effects on host populations and commercial and sport fisheries, with accompanying severe socio-economic impacts on human populations.

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15 http://www.gaalliance.org

In some countries, the private sector has adopted so called 'better' or 'best' management practices (BMPs), which may have contributed to the prevention of on-farm disease problems. Although the state sector has also assisted these efforts through the development of expertise, infrastructure and capacity for health management, shrimp culture and capture fisheries in most countries remain vulnerable to further introductions of transboundary diseases. There is much further work that can be done however, and this report includes recommendations as to what this might comprise.

6.2 Biodiversity

Little is currently known about the effects of cultured shrimp on wild populations and biodiversity. The fears are that alien cultured shrimp could escape to the wild and then either displace native shrimp populations by out-competing them, interbreeding with them, or killing them through contamination with fatal pathogens (i.e. viruses) to which they are susceptible.

Some of the scant research done in this area has indicated that much of the genetic structure of wild populations appears to reflect historical events on large biogeographical scales, rather than resulting from patterns of present-day dispersal. Benzie (2000) found no conclusive evidence that aquaculture escapees had altered the genetic constitution of wild stocks of *P. monodon* in Thailand. However, this research was conducted before the introduction of *P. vannamei*, so the effects of escapees of this species (in Thailand at least) remain unknown.

The escape of *P. vannamei* from shrimp farms into the surrounding environment can be expected as a result of accidental release during harvesting as well as mass escape during flooding events. Some release from hatcheries may also be expected unless comprehensive measures are taken to reduce escapes. In Thailand, floods in Surat Thani and Pranburi in 2003 for example led to several million *P. vannamei* escaping to the coastal environment. Not surprisingly, *P. vannamei* therefore has been reported in fisherfolk's catches on Andaman and Gulf of Thailand coasts. No detailed information on catches is available, but numbers have not been reported as large. There are also no reports from fisherfolk or Thai Department of Fisheries officers, that escapes of *P. vannamei* have led to any perceivable impact on wild shrimp populations in any Thai coastal area. However, further ecological research is needed on *P. vannamei* in the wild and its impacts on fisherfolk's catches and native species.

Native Penaeid shrimp species support fisheries of commercial importance in several Asian countries, and crustaceans and shrimp are also significant in artisanal coastal fisheries.

The main risk would be if competition occurs with native species where *P. vannamei* occupies the same "ecological niche" or in other ways cause competition for habitat (space), feed or adversely interfere with breeding behaviour or breeding success. If *P. vannamei* occupies a 'vacant' niche (which is unlikely), or the abundance of other shrimp species is limited by other factors, (which is possible), then *P. vannamei* has the potential to add to shrimp catches. However, if *P. vannamei* does not breed and become established in the wild any impacts are likely to be localized and limited in time.

Some instances of cultured shrimp escaping to and becoming established in the wild are known from the USA. *Penaeus monodon* (originally from Hawaii) were introduced accidentally into the Atlantic coast of the USA when they were accidentally released by the Waddell Mariculture Center in 1988. Commercial shrimpers have subsequently captured *P. monodon* as far south as Florida, although it is not believed to be established in the USA (McCann *et al.*, 1996). Similarly, *P. monodon*, *P. vannamei*, *P. stylirostris* and *P. japonicus* are all known to have escaped culture facilities in Hawaii, although none are known to be locally established (Brock, 1992; Eldridge, 1995).

Taura Syndrome Virus (TSV) has been documented in wild PL (in Ecuador in 1993) and adult (off the Pacific coast of Honduras, El Salvador and southern Mexico since 1994) *P. vannamei*. The infected adults showed high mortalities and developed diagnostic lesions from the disease. Thus, viruses such as TSV have been proven to infect and cause mortality in wild shrimp populations, but their effects on commercial Penaeid shrimp fisheries remain unstudied and unknown (Lightner and Redman, 1998b).

In the Pacific Islands, *P. japonicus* has escaped culture facilities, but has failed to become established, although *P. merguiensis* is known to have escaped and become established in the wild off Fiji (Eldridge, 1995). The effects of this on the wild shrimp populations, however, remain unknown.

If there is establishment of breeding populations of *P. vannamei* in the wild, then competition with native species will be sustained and the potential for longer-term impacts on aquatic biodiversity in coastal waters will become more significant. The risks of such consequences do exist and suggest the need for great caution.

Despite the fact that the species has been widely introduced, a comprehensive study of the literature carried out for this report and the information available from other countries in Asia and in the Americas did not find any evidence of *P. vannamei* becoming established in the wild outside of its range (*i.e.* it may not become an easily "invasive" species). However, there is a need for further field research, as there was insufficient information available on the natural breeding habits of *P. vannamei* to make any further assessment of this issue, or the degree of potential competition or interaction with native species. Thus, in the absence of good scientific evidence, a precautionary approach should be adopted to *Penaeus vannamei* farming, if animals are to be introduced.

6.3 Environmental effects

Penaeus vannamei is tolerant of a wide range of salinities, especially very low salinity. This means that it is currently cultured in both inland and coastal areas. Just as with the farming of other Penaeid species, this raises a number of potential environmental issues. Environmental concerns for *P. vannamei* culture include potential impacts on: (1) natural and agricultural habitats, caused by poorly sited or managed shrimp farms; and (2) effects of farm effluents on water quality in inland and coastal areas[16].

Although there are differences in the locations where *P. vannamei* and native Penaeid species are farmed, there are likely to be no major differences in the impacts on habitats. In Asia, *Penaeus vannamei* is commonly farmed in shrimp farms that have previously produced *P. monodon.* Therefore, no significant new impacts on the habitats of coastal or agriculture areas are anticipated. Although there has been some expansion of *P. vannamei* into new farming areas, impacts of such farming on the surrounding natural environment is not considered significant, provided adequate measures are taken. As in the case of *P. monodon,* particular care is essential when culturing *P. vannamei* in areas with seasonal freshwater. Normal siting practices and good farm management for reducing impacts on surrounding habitats should be followed. Where farms practice limited water exchange, recycling of pond water or use of effluent treatment, then impacts on the surrounding environment can be reduced or eliminated. The trend in farming of *P. vannamei* in Asia and the Americas is towards the use of limited water exchange and closed or semi-closed farming systems, thus the impacts on the environment are less.

One potentially positive environmental impact of farming of *P. vannamei* concerns the differences in behaviour and feeding habits compared to *P. monodon*. *Penaeus vannamei* spends more time in the water column, and tends not to burrow into the bottom sediment allowing it to be harvested more easily than *P. monodon*. It is possible to harvest without complete draining of the pond, thereby avoiding the stirring up of poor quality bottom sediments. Harvesting using the non-draining method offers an opportunity to avoid the discharge of harvesting effluent that is high in nutrients and organic matter.

Another significant advantage of *P. vannamei* is its feeding habits and requirements for lower protein diets compared to *P. monodon*, which will reduce pressure on fishmeal and fish oil requirements. *Penaeus*

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[16] The consortium on shrimp farming and the environment has produced numerous thematic reviews and case studies related to this subject for more information please visit http://www.enaca.org

vannamei requires lower protein (and hence cheaper) diet in culture than *P. monodon and* is more able to utilize the natural productivity of shrimp ponds, even under intensive culture conditions, and with better feeding efficiency. In Thailand, typical commercial grow-out feeds for *P. vannamei* contain 35 percent protein and cost 10-15 percent less than the 40-42 percent protein feeds for *P. monodon*.

More efficient feeding practices and reduction in the use of fish meal can lead to reduced problems of nitrogen discharge and more efficient use of natural feed resources, per unit of production. Nutrient budgets in the literature for *P. vannamei* and *P. monodon* culture show that *P. vannamei* farming makes more efficient use of nitrogen than *P. monodon* culture, principally due to the lower protein requirements of *P. vannamei*.

6.4 Viral diseases

In 1989, 6 viruses were known to affect Penaeid shrimp, but by 1997 more than 20 viruses were identified as having affected wild stocks and commercial production (Hernandez-Rodriguez *et al.*, 2001). The OIE now lists seven viral diseases of shrimp in the Aquatic Animal Health Code (OIE, 2003), which are considered to be transmissible and of significant socio-economic and/or public health importance. These viral diseases are: white spot disease (WSSV), Yellow Head disease (YHV), Taura syndrome virus (TSV), spawner-isolated mortality virus disease (SMV), tetrahedral baculovirosis (*Baculovirus penaei* – BP), spherical baculovirosis (*Penaeus monodon*-type baculovirus) and Infectious hypodermal and haematopoietic necrosis (IHHNV) (OIE, 2003; OIE website[17]). All OIE member countries are obliged to report these diseases so that disease spread can be monitored and legislation instituted to prevent disease spread. However, the member countries do not always comply with these requirements.

Penaeus vannamei and *P. stylirostris* are known to be carriers of the following viral diseases: WSSV, BP, IHHNV, REO, LOVV and TSV. These viruses can be transmitted to native wild Penaeid shrimp populations (Overstreet *et al.*, 1997; JSA, 1997; Timothy Flegel, per. com.).

Penaeus monodon are known carriers of: WSSV, YHV, MBV, IHHNV, BMNV, GAV, LPV, LOVV, MOV and REO (Lightner, 1993; Flegel, 2003).

Taura Syndrome Virus (TSV)

Perhaps the biggest concern to Asian countries already or currently wanting to import *P. vannamei* is the possibility of introducing TSV. Despite original work suggesting Taura syndrome (TS) was caused by a toxic pesticide, it is now known that a single or perhaps several very closely related strains (mutations) of the Taura syndrome virus (TSV) are responsible for the TS pandemic in the Americas (Brock *et al.*, 1997; OIE website). TSV is a single strand RNA virus and hence susceptible to mutations, causing more concern, and is closely related to other insect viruses (Gulf States Marine Fisheries Commission website[18]; Flegel and Fegan, 2002).

Taura Syndrome Virus was first identified from farms around the Taura river in Ecuador in 1992 and subsequently spread rapidly to the whole of Latin and North America within three years. TSV spread first throughout Ecuador and to Peru (1993), Colombia (Pacific and Atlantic coasts), Honduras, Guatemala, El Salvador, Nicaragua, Hawaii, Florida and Brazil (1994), Mexico, Texas, South Carolina and Belize (1995/96) (Brock *et al.*, 1997; Lightner and Redman, 1998; GSMFC website), and subsequently Asia including Mainland China and Taiwan Province of China (from 1999) (OIE website; Flegel and Fegan, 2002a), and most recently Thailand (2003) (Timothy Flegel, per. com.), probably through the regional and international transfer of live PL and broodstock *P. vannamei*.

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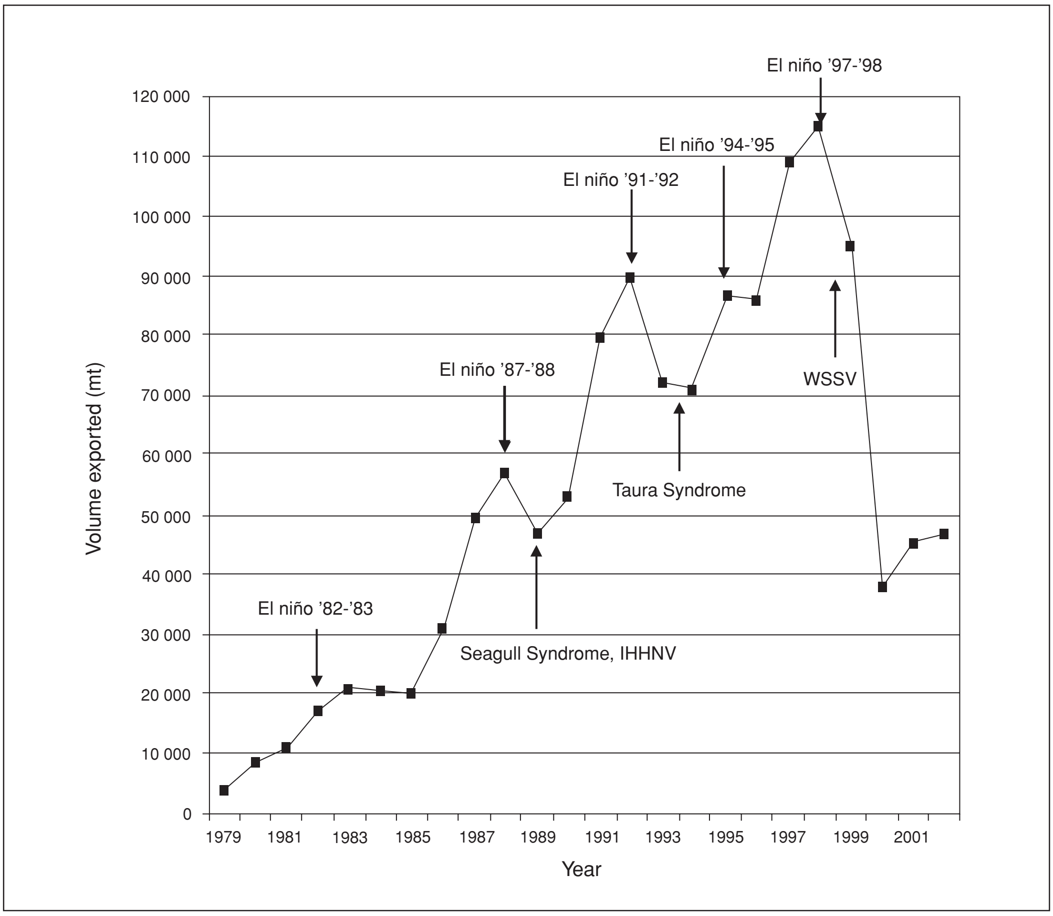
[17] http://www.oie.int

[18] http://nis.gsmfc.org/

Taura syndrome caused serious losses in revenue throughout Latin America in the 1990s. It has been suggested that TSV caused direct losses (due to shrimp mortality) of US$ 1-1.3 thousand million in the first three years in Latin America. However, indirect losses due to loss of sales, increased seed cost and restrictions on regional trade were probably much higher (Brock *et al.*, 1997; Hernandez-Rodriguez *et al.*, 2001).

In 1992, Ecuador was producing close to 100 000 metric tonnes of *P. vannamei* worth some US$ 880 million (FAO Fishstat estimate is US$ 551 million). Lightner (1996a) estimated that a 30 percent reduction in production (to 70 000 metric tonnes) in subsequent years represented a loss of up to US$ 400 million per year from Ecuador alone (Figure 2). However, *P. vannamei*, even without the benefit of selective breeding (still in its infancy at that stage) were quickly able to gain some tolerance to TSV, so that Ecuador had recuperated to a production of 129 600 metric tonnes worth US$ 875 million by 1998 (FAO Fishstat figure is US$ 648 million). Then in late 1999, WSSV hit Ecuador and production rates declined once again (Rosenberry, 2000).



Source: Camara Nacional de Acuacultura website – http://www.cna-ecuador.com

Figure 4: Exports of shrimp (mt) from Ecuador 1979-2002 and environmental/disease events

Little is known regarding the prevalence of TSV in wild shrimp populations, and although it has been detected in wild *P. vannamei* from the Americas and in wild *P. monodon* in Taiwan Province of China, there is no evidence that it has impacted wild shrimp populations (Brock, 1997; GMFS website; OIE website). Taura syndrome so far appears to occur largely as a sub-clinical infection in populations of wild shrimp (Brock *et al.*, 1997). Although *P. monodon* and *P. japonicus* appear largely unaffected, the potential impact of TSV on native stocks of *P. indicus* and *P. merguiensis* in Asia remains unknown, but a definite cause for concern.

The mechanism of spread of TSV is still uncertain, although initial theories concentrated on the spread through contaminated PL and broodstock between farms (Lightner, 1995 and 1996b; Garza *et al.*, 1997). Limited data have shown that TSV was introduced to Colombia and Brazil through contaminated broodstock from Hawaii (Brock *et al.*, 1997). These broodstock were untested for TSV since it was not yet known that Taura syndrome had a viral cause. Such cases demonstrate once again more of the problems involved with transboundary movements of animals, even supposedly SPF ones. Recent research has shown that mechanical transfer through insect and avian vectors may be an equal or even more likely route of infection. TSV has sometimes been found in tissue bioassays of the water boatman (*Trichocorixa reticulata*), an estuarine insect common worldwide, and virus-containing extracts of this insect have been shown to induce infection in SPF *P. vannamei* under laboratory conditions (Lightner, 1995). Patterns of the spread and mortality of *P. vannamei* in Texas have also suggested that the ingestion of infected insects is the probable mechanism of spread of TSV (Thompson *et al.*, 1977).

Infective TSV has also been demonstrated in the faeces of shrimp-eating seagulls (*Larus atricilla*) collected near ponds infected with TSV in Texas, USA (Lightner, 1996a; Garza *et al.*, 1997). Experimental results have also shown that healthy shrimp can be infected through injection of cell-free homogenates prepared from infected shrimp, and by direct feeding on infected shrimp (Brock *et al.*, 1995; Hasson *et al.*, 1995). Taura syndrome virus has also been shown to remain infective after one or more freeze-thaw cycles, indicating the possibility of regional transmission through infected frozen shrimp (Lightner, 1995; Brock *et al.*, 1997). With proper disinfection procedures and controls, however, this route is currently considered to be low-risk (Flegel and Fegan, 2000b; Flegel, 2003).

Taura syndrome virus is highly infective for *P. vannamei*, *P. setiferus* and *P. schmitti*. *Penaeus stylirostris* can be infected by injection, but appear to be highly refractory to TSV and have demonstrated tolerance to TS in growing areas affected by this disease. Other species including *P. aztecus*, *P. duorarum*, *P. monodon*, *P. japonicus* and *P. chinensis* have been experimentally infected, developed the disease and remained carriers, but show some resistance (Lightner, 1996a; Brock *et al.*, 1997; Overstreet *et al.*, 1997; GSMFC website; OIE website). Interestingly, like *P. stylirostris*, *P. monodon* and *P. japonicus* appear highly refractory to TSV, and although it retards growth rates, they remain asymptomatic and the virus has not yet been demonstrated to cause mortality in these species (Timothy Flegel, per. com.; Brock *et al.*, 1997; OIE website). However, since TSV is an RNA virus, with a high propensity to mutate, there is no guarantee that it will not mutate into a more virulent form for native Asian shrimp (as it did in Central America) (Flegel and Fegan, 2002; Lightner, 2002).

Taura Syndrome Virus has already been detected in *P. vannamei* in Mainland China (starting in 1999/2000) and Taiwan Province of China (from 1999) (OIE website; Tu *et al.*, 1999; Yu and Song, 2000) with 19 cases reported to OIE from Taiwan Province of China in 1999, ten (resulting in 700 000 cases and 200 000 deaths) in 2000, and seven (resulting in 500 000 cases and 50 000 deaths) in 2001. Recently, TSV has been identified in Thailand (Timothy Flegel, per. com.), but not officially reported to OIE, despite being a listed disease. TSV has not yet (in 2003) been reported from Viet Nam, Indonesia (Taw *et al.*, 2002), India or Malaysia (Dato Mohamed Shariff, per. com.).

The Taura syndrome virus tends to infect juvenile shrimp within two to four weeks of stocking ponds or tanks (0.1-1.5 g body weight) and occur largely within the period of a single moult cycle. In the acute phase of the disease, during pre-moult the shrimp are weak, soft-shelled, have empty digestive tracts and diffuse expansion of the red chromatophores, particularly in the tail (hence the common name – red tail disease) (Lightner *et al.*, 1995). Such animals will usually die during moulting (5-95 percent), although the reasons for the large variability in survival rates remains unknown; adult shrimp are known to be more resistant than juveniles (Brock *et al.*, 1997). Those shrimp that survive will show signs of recovery and enter the chronic phase of the disease. Such shrimp will show multiple, randomly distributed, irregular, pitted, melanised lesions of the cuticle. These gross or microscopic lesions will persist, but may be lost during moulting, the shrimp thereafter appearing and behaving normally. However, although the shrimp may then be resistant to recurrence of the disease, they often remain chronic, asymptomatic carriers of TSV for life (Lightner, 1996b; Brock *et al.*, 1997; GSMFC website; OIE website), as has been shown by bioassays (Brock *et al.*, 1995).

Standard histological and molecular methods may be used for detection, diagnosis and surveillance, although specific DNA probes applied to *in situ* hybridization assays with paraffin sections currently provide the greatest diagnostic certainty of this virus (OIE website). RT-PCR assays can also be used providing advantages of larger sample sizes and non-lethal sampling for broodstock. Additionally, live shrimp bioassays and serological methods with monoclonal antibodies can also be used for diagnosing infections with TSV. The full set of current diagnostic procedures using all of these methods is found in the OIE Diagnostic Guide available on the OIE website.

Eradication methods for TSV in culture facilities are possible and depend upon total destruction of infected stocks, disinfection of the culture facility, avoidance of reintroduction of the virus (from nearby facilities, wild shrimp and carriers) and restocking with TSV-free PL produced from TSV-free broodstock (Lotz, 1997; Lightner and Redman, 1998a; OIE website).

Other methods suggested for controlling the virus include: switching to the refractory *P. stylirostris*, and (similar to those suggested for other viruses): maintenance of optimal environmental conditions, weekly applications of hydrated lime (CaOH) at 50 kg/ha, polyculture with fish (to consume dying and dead carriers) and development of TSV resistant lines of *P. vannamei* (Brock *et al.*, 1997). In the past few years, considerable success has been achieved in the development of families and lines of *P. vannamei* which are resistant to TSV (Argue *et al.*, 2002).

Most of the SPF *P. vannamei* suppliers from Hawaii and Florida now offer stocks of *P. vannamei* which have demonstrated resistance to TSV (SPF and SPR) (Table 7). Genetic selection programmes run throughout the Americas have also resulted in the production of SPR lines for TSV. The use of such SPR lines enabled the Latin American industry to recuperate from the worst of the TSV pandemic within three to four years. However, importation of such lines must be done with caution, since non-SPF animals, even though resistant to TSV, may still act as carriers and can result in the introduction of TSV into areas of Asia currently free from the disease.

In the latest edition of the OIE aquatic animal health code, guidelines are offered for countries currently declared free from TSV for importations of shrimp. These guidelines suggest that the competent authority of such countries should only import live *P. vannamei* and *P. stylirostris* (eggs, nauplius, PL, juveniles or broodstock) from either countries or certified regions or aquacultural establishments declared free from TSV (OIE, 2003). The competent authority of the importing country should require that each shipment be accompanied by an international aquatic animal health certificate issued by the competent authority of the exporting country. This certificate must certify, on the basis of an official crustacean health surveillance scheme (run according to the OIE manual) that the country, region or establishment is officially declared TSV-free. The same guidelines exist for importation of dead shrimp.

Aquacultural establishments, zones within countries, or countries that are considered TSV-free, are those which: have been tested in an official crustacean health surveillance scheme for a minimum two years using the procedures described in the OIE manual, without detection of TSV in any susceptible host species of shrimp[19]. Additionally for aquacultural establishments, they must be supplied with water that has been suitably disinfected and have barriers preventing contamination of the establishment and its water supply. New or disinfected facilities, may be declared free from TSV in under two years if all other requirements are met (OIE website).

Whilst this degree of control may be possible in large-scale highly organized shrimp farms, the reality is that most farms are too small or disorganized to undertake such comprehensive measures. The lack of supporting infrastructure in regulation, testing and diagnosis is an additional constraint. This problem is not confined to Asia where farms are typically very small, but also occurs in Latin America where farms are far larger.

Infectious Hypodermal and Haematopoietic Necrosis Virus (IHHNV)

This virus was first discovered in *P. vannamei* and *P. stylirostris* in the Americas in 1981, starting in Hawaii (Lightner, 2002). However, it was probably not an indigenous virus, but was thought to have been introduced along with live *P. monodon* from Asia. IHHNV has probably existed for some time in Asia without detection due to its insignificant effects on *P. monodon*, the major cultured species in Asia, meaning that nobody was looking for it. Recent studies have revealed geographic variations in IHHNV isolates, which suggested that the Philippines were the source of the original infection in Hawaii, and subsequently in most shrimp farming areas of Latin America (Tang *et al.*, 2002).

IHHNV is a small single-stranded DNA-containing parvovirus, which is only known to infect only Penaeid shrimp. "Natural" infections are known to have occurred with *P. stylirostris*, *P. vannamei*, *P. occidentalis* and *P. schmitti*, while *P. californiensis*, *P. setiferus*, *P. aztecus* and *P. duorarum* were proven susceptible experimentally in Latin America. *Penaeus monodon*, *P. semisulcatus*, *P. japonicus* and *P. chinensis* and others are known to be susceptible in Asia (OIE website).

Catastrophic epidemics and multi-million dollar losses in shrimp culture have been attributed to IHHNV (GSMFC website) and it has had significant negative consequences for cultured *P. vannamei* in the Americas during the 1990s (Lightner, 1996a). Some indication of its impact may be gauged from work done in intensive culture systems in Hawaii, which improved yields by 162 percent through the stocking of shrimp bred specifically to be IHHNV resistant (Flegel and Fegan, 2002).

IHHNV did not cause significant problems in Ecuador until the warm waters and abundant wild seed (acting as latent carriers of the disease) associated with the strong El Niño of 1987/88 caused an epidemic from 1987 onwards (Jiménez *et al.*, 1999) (Figure 4). Recent use of domesticated and selected strains of *P. vannamei* instead of wild PL has more recently reduced the severity of the epidemic, indicating the utility of such selections in combating viral pathogens such as IHHNV.

IHHNV was also largely responsible for the temporary cessation of Mexican commercial shrimp fishing for several years once it escaped from farms into the wild shrimp populations (Lightner, 1996). IHHNV is now commonly found in cultured and wild Penaeid on the Pacific coast of Latin America from Mexico to Peru, but not yet from the eastern coast of Latin America. It has also caused problems for the Hawaiian broodstock and farm-based culture industries. IHHNV has also been reported from both cultured and wild Penaeid from throughout the Indo-Pacific region (OIE website).

IHHNV is fatal to *P. stylirostris* (unlike *P. vannamei*), which, although highly resistant to TSV (leading to its comeback in the culture industry of Mexico in the late 1990s), are extremely sensitive to IHHNV (causing 90 percent mortality), especially in the juvenile stages (Lightner, 1996; OIE website). However, IHHNV has not been associated with mass mortalities of *P. stylirostris* in recent years (Tang *et al.*, 2003),

[19] A new FAO document on surveillance and zoning provides advice and guidance for countries to establish surveillance and zoning programmes to reduce disease risks. Subasinghe, R.P.; McGladdery, S.E.; Hill, B.J. (eds.). Surveillance and zoning for aquatic animal diseases. *FAO Fisheries Technical Paper* No. 451. Rome, FAO. 2004. 73 p.

probably due to the selection of IHHNV-resistant strains (*i.e.* the so-called “supershrimp” *P. stylirostris*, Tang and Lightner, 2001). This emphasises the potential benefits offered from the domestication and genetic selection of cultured shrimp.

Penaeus vannamei are fairly resistant to this disease with certain modifications in management practices. In *P. vannamei*, IHHNV can cause runt deformity syndrome (RDS), which typically results in cuticular deformities (particularly bent rostrums), slow growth, poor feed conversion and a greater spread of sizes on harvest, all combining to substantially reduce profitability. These effects are typically more pronounced where the shrimp are infected at an early age, so strict hatchery biosecurity including checking of broodstock by PCR, or the use of SPF broodstock, washing and disinfecting of eggs and nauplii is essential in combating this disease. Even if IHHNV subsequently infects the shrimp in the grow-out ponds, it has little effect on *P. vannamei* if the PL stocked can be maintained virus free (Centre for Tropical and Subtropical Aquaculture, 1996).

Some strains of IHHNV, however, have recently been found to be infectious for *P. vannamei*, including a putative strain collected from Madagascan *P. monodon* (Tang *et al.*, 2002) and a putative attenuated strain in an American laboratory (Laramore *et al.*, 2002). In addition, recent laboratory studies with *P. stylirostris* has shown that juveniles that are highly infected with IHHNV (by feeding them with IHHNV-infected tissue) were able to show 28-91 percent survival three weeks after subsequent infection with WSSV (by feeding them with WSSV-infected tissue), whilst control animals suffered 100 percent mortality within five days (Tang *et al.*, 2003). Surviving shrimp were found to be heavily infected by IHHNV, but had at most only light infection with WSSV which was not enough to kill all of them. Similar trials showed that neither IHHNV pre-infected *P. vannamei* nor IHHNV-resistant *P. stylirostris* (SPR “Supershrimp”) were able to tolerate subsequent WSSV infections. Nonetheless, these results raise the question whether exposing shrimp to putative strains of IHHNV may prevent them from getting infected by an infectious strain of IHHNV or possibly WSSV.

IHHNV typically causes no problems for *P. monodon* since they have developed tolerance to it over a long period of time, but they may suffer from runt deformity syndrome (RDS) (OIE website). *Penaeus merguiensis* and *P. indicus* meanwhile appear refractory to the disease (Flegel and Fegan, 2002). They are, however, life-long carriers of the disease and so could easily pass it onto *P. vannamei*, which typically suffer from slow growth (RDS) when exposed to IHHNV. This presents a potential problem if the two species are cultured in close proximity at any phase of their life cycle (Timothy Flegel, per. com.). This should be a cause for great concern for *P. vannamei* farms that are currently being established throughout Asia.

As with most important shrimp viruses, transmission of IHHNV is known to be rapid and efficient by cannibalism of weak or moribund shrimp, although water-borne transfer due to cohabitation is less efficient. Vertical transmission from broodstock to larvae is common (OIE website) and has been shown to originate from the ovaries of infected females (whilst sperm from infected males was generally virus-free). Although the embryos of heavily infected females may abort, this is not always true and selection of IHHNV-free broodstock (by nested PCR) and disinfection of eggs and nauplii would help ensure production of virus-free PL (Motte *et al.*, 2003).

As with TSV, IHHNV may be transmitted through vectors such as insects, which have been shown to act as carriers for the disease. However, their mode of action is thought to be mechanical rather than real, as insect extracts do not react to *in situ* hybridisation tests for IHHNV (Timothy Flegel, per. com.).

The probability that IHHNV in frozen shrimp can cause problems is suggested from OIE data that IHHNV remains infectious for more than 5 years of storage at minus 20ºC (OIE website).

Gross signs of disease are not specific to IHHNV, but may include: reduced feeding, elevated morbidity and mortality rates, fouling by epicommensals, bluish coloration, whilst larvae PL and broodstock rarely show symptoms (OIE website).

Diagnosis and detection methods include DNA probes for dot blot and *in situ* hybridisation and PCR techniques (including real-time PCR, Tang and Lightner, 2001) as well as histological analysis of H&E-stained sections looking for intracellular, Cowdrey type A inclusion bodies in ectodermal and mesodermal tissues. The full procedures for all these tests can be found in the OIE website.

One of the big problems with IHHNV is its eradication in facilities once they have been infected. The virus has been shown to be highly resistant to all the common methods of disinfection including chlorine, lime, formalin and others in both ponds and hatcheries (CTSA, 1996; Scurra, per. com.). Complete eradication of all stocks, complete disinfection of the culture facility and avoidance of restocking with IHHNV-positive animals, i.e. through the use of screened or SPF animals, has been recommended (OIE website).

White Spot Syndrome Virus (WSSV)

This virus is now and has for some time been the most serious threat facing the shrimp farming industry in Asia (since 1992) and Latin America (since 1999). It is an extremely virulent pathogen with a large number of host species (Flegel *et al.*, 1997; Lightner and Redman, 1998b).

This disease is probably the major cause of direct losses of up to US$ 1 thousand million per year since 1994 in Asia. Similarly, in Latin America, losses due to WSSV have been substantial. For example, in the first six months of its first appearance in Ecuador, it was estimated to have caused a loss of 63 000 metric tonnes of cultured *P. vannamei* and *P. stylirostris*, worth some US$ 280 million. In addition, indirect losses in hatchery, feed and packing plant capacities and so on resulted in lost earnings and the loss of 150 000 jobs in the sector (Alday de Graindorge and Griffith, 2000). Data from the Ecuadorian Camara Nacional de Acuacultura (CNA) show that due to WSSV, shrimp exports fell from 115 000 metric tonnes (mt) in 1998 to 38 000 mt in 2000, and have only recovered slightly to 47 000 mt in 2002, and perhaps 50 000 metric tonnes in 2003 (CNA website) (Figure 2). This equates to a total direct loss (alone) of some 267 000 metric tonnes of shrimp worth nearly US$ 1.8 thousand million (if production had remained static at 1998 levels) between 1999 and mid-2003.

Similar problems have occurred throughout Central and South America, with the exception of Brazil and Venezuela, which remain WSSV-free due to the prompt and effective closure of their borders to all crustacean imports in 1999. The United States also managed to eradicate WSSV from its shrimp culture industry in 1997 after initial losses through implementation of biosecurity measures, including the use of all SPF broodstock (Lightner, 2002), although there are reports of its recent re-emergence in Hawaii in 2004 (Shrimp News Website[20]).

WSSV is a large double-stranded DNA baculovirus (Lightner, 1996). Other names for probably the same viral complex include Chinese baculovirus (CBV), White spot syndrome baculovirus complex (WSBV), Mainland China's Hypodermal Hepatopoietic Necrosis Baculovirus (HHNBV), Shrimp Explosive Epidermic Disease (SEED), Penaeid Rod-shaped DNA Virus (PRDV), Japan's Rod-shaped Nuclear Virus (RV-PJ) of *P. japonicus*, Thailand's Systemic Ectodermal and Mesodermal Baculovirus (SEMBV) of *P. monodon*, red disease and white spot virus or disease (GSMFC website).

WSSV was first reported in farmed *P. japonicus* from Japan in 1992/93, but was thought to have been imported with live infected PL from Mainland China. At roughly the same time, it was discovered in cultured *P. monodon*, *P. japonicus* and *P. penicillatus* in Taiwan Province of China and then in *P. monodon* in southern Thailand (Lightner and Redman, 1998b). WSSV then spread rapidly throughout most of the shrimp growing regions of Asia, probably through infected broodstock and PL *P. monodon*. Then, in 1995, it was detected for the first time in farmed *P. setiferus* in Texas. It was also shown to be infective experimentally to both *P. vannamei* and *P. stylirostris* (Tapay *et al.*, 1996). WSSV did not reach

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the Philippines, which had an effective government ban on live imports, until an illegal introduction of Chinese PL *P. monodon* in 2000 (Flegel and Fegan, 2002).

Other susceptible host species include the shrimp species *P. merguiensis*, *Metapenaeus ensis*, *Metapenaeus monoceros* and various crab species, whilst *Palaemon setiferus*, *Euphausia superba*, *Metapenaeus dobsoni*, *Parapenaeopsis stylifera*, *Solenocera indica*, *Squilla mantis*, *Macrobrachium rosenbergii* and a range of crab species can act as latent carriers, although *Artemia* appear unsusceptible (Flegel *et al.*, 1997; Hossain *et al.*, 2001).

Later, in 1999, WSSV began affecting Latin America from Honduras, Guatemala, Nicaragua and Panama in Central America to Ecuador and Peru in the south and later to Mexico. The only shrimp farming countries to remain free of WSSV in Latin America are Brazil and Venezuela, who (like the Philippines) both placed immediate and effective bans on the importation of live crustaceans and developed their domestication programmes for producing virus-free seedstock.

The mode of transmission of WSSV around Asia was believed to be through exports of live PL and broodstock. The outbreaks in Texas in 1995 and then Honduras in 1999, followed by Spain and Australia in 2000-2001, were thought to be due to the virus escaping from processing plants which were importing and processing frozen shrimp from infected parts of Asia, although this has never been proven (Lightner, 1996a and 2002; GSMFC website). Regardless of their origin, isolates of WSSV have shown little genetic or biological variation, suggesting that the virus emerged and was spread from a single source (Lightner, 2002).

WSSV, as with most viral diseases, is not thought to be truly vertically transmitted, because disinfection of water supplies and the washing and/or disinfection of the eggs and nauplius is successful in preventing its transmission from positive broodstock to their larvae. Instead, it is generally believed that the virus sticks to the outside of the egg, since, if it gains entry to the egg, it is rendered infertile and will not hatch. Thus, using proper testing and disinfection protocols, vertical transmission can be prevented in the hatchery, as proven by the Japanese who to date have successfully eliminated WSSV from captive stocks in the country through disinfection and PCR checking of broodstock and nauplii (Timothy Flegel, per. com.).

Using mathematical epidemiology modelling, Soto and Lotz (2001) showed that WSSV was more easily transmitted through ingestion of infected tissues than through cohabitation with infected hosts, and that *P. setiferus* was much more susceptible than *P. vannamei* to infection.

Although it is clear that live Penaeids can carry the virus and infect new hosts through reproduction (transmission from broodstock to larvae), consumption or cohabitation with diseased or latent carriers, and that it is possible for frozen shrimp to be infective, other modes of transmission are also possible. For example, Australia is considered WSSV (and YHV)-free, although WSSV was detected in the Northern Territories in 2000 associated with imported bait shrimp, before being eradicated (East *et al.*, 2002).

Data regarding the presence and effects of WSSV in wild shrimp populations in infected countries is scarce, but it is known to be present in wild shrimp in both Asia and Latin America.

WSSV infects many types of ectodermal and mesodermal tissues, including the cuticular epithelium, connective, nervous, muscle, lymphoid and haematopoietic tissues. The virus also severely damages the stomach, gills, antennal gland, heart and eyes. During later stages of infection, these organs are destroyed and many cells are lysed. The shrimp then show reddish colouration of the hepatopancreas and the characteristic 1-2 mm diameter white spots (inclusions) on their carapace, appendages and inside surfaces of the body. They also show lethargic behaviour and cumulative mortality typically reaches 100 percent within two to seven days of infection (GSMFC website).

Increasingly, since the late 1990s, it has become clear that the presence of WSSV in a pond does not always lead to disaster. Work in Thailand has shown that outbreaks are usually triggered from latent

P. monodon carriers by some environmental changes, probably related to osmotic stress through changes in salinity or hardness or rapid temperature changes (Flegel *et al.*, 1997). Similarly in Latin and North America, fluctuations in temperature have been shown to induce mortalities of infected *P. vannamei*. However, there have been conflicting reports about constant temperatures which have been reported to: limit mortality due to WSSV at 18ºC or 22ºC and induce 100 percent mortality at 32ºC in the US (Overstreet and Matthews, 2002), yet induce mortality at less than 30ºC and protect from it at greater than 30ºC in Ecuador (Matthew Briggs and Neil Gervais, per. com.).

Additionally, three to four years of genetic selection work (selection of shrimp surviving WSSV outbreaks) on the domesticated stocks of *P. vannamei* appear to have resulted in enhanced resistance to WSSV in Ecuador (Matthew Briggs and Neil Gervais, per. com.). Thus the culture industries for *P. vannamei* in Central and South America have been slowly recuperating since the start of the WSSV epidemic in 1999. For example, Ecuador was exporting 115 000 metric tonnes in 1998, which dropped to only 38 000 metric tonnes in 2000 after the arrival of WSSV in 1999. Subsequently, Ecuador has recovered to export an estimated 50 000 metric tonnes in 2003 (INP and CAN (Ecuador) websites).

Prevention methods are similar to those with TSV. All live and frozen shrimp should be checked by PCR prior to importation from infected areas to those currently disease-free. Broodstock should be PCR screened before breeding. PL should also be PCR screened before stocking into ponds, as this has been proven to result in a higher percentage of good harvests (Pornlerd Chanratchakool, per. com.). PCR is not an infallible method for detection of WSSV, but it is the best diagnostic procedure currently available. Washing and disinfection of eggs and nauplii has also been shown to prevent vertical transmission of WSSV from infected broodstock to larval stages. Feeding with fresh crab and other crustaceans to broodstock should be avoided. Polyculture techniques with mildly carnivorous fish species (such as Tilapia spp.) has also proven effective at limiting the virulence of WSSV in ponds, as the fish can eat infected carriers before they become available to the live shrimp.

The white spot virus only remains viable in water for 3-4 days, so disinfection of water used for changes and fine screening is effective in preventing transmission. Dose rates of 70 ppm formalin have been shown to prevent transmission and not cause any harm to shrimp (Flegel *et al.*, 1997). In addition, all effluent from farming or processing operations with the possibility of WSSV infections should be disinfected (i.e. with formalin or chlorine) prior to discharge (Flegel *et al.*, 1997).

WSSV can be detected by using PCR, or with probes for dot-blot and *in situ* hybridisation tests. It can also be visually diagnosed through the presence of the characteristic white spots (although these are not always present in infected animals). WSSV can be confirmed histologically (particularly for asymptomatic carriers) by the presence of large numbers of Cowdrey A-type nuclear inclusions and hypertrophied nuclei in H&E-stained sectioned tissues, or simply by rapid fixation and staining of gill tissue and microscopic examination (Flegel *et al.*, 1997). Standard diagnostic techniques are provided on the OIE website.

Yellow Head Virus (YHV)

Yellow Head Virus was the first major viral disease problem to affect Asian shrimp farms when it was diagnosed as causing extensive losses in Thailand starting in 1990/91. YHV and its close relatives GAV and LOVV are single stand RNA viruses, similar to TSV.

The first records of this virus were from *P. monodon* ponds in Eastern Thailand in 1990/91. By 1992, it had moved to Southern Thailand and was causing substantial mortality. YHV is prevalent wherever *P. monodon* are cultured, including Thailand, Taiwan Province of China, Indonesia, Malaysia, Mainland China, the Philippines and Viet Nam. It may also have been responsible for the first major crashes in Taiwan Province of China in 1987 (GSMFC website; Flegel *et al.*, 1997; Lightner and Redman, 1998b).

Losses due to YHV continued, although the severity and frequency of outbreaks declined sharply by 1994 when WSSV became the prime cause of mortality in cultured *P. monodon*. Although research has shown that YHV is still present in culture ponds, the shrimp now rarely show gross symptoms and are latently infected. There thus appears to be a currently unknown mechanism for rapid tolerance or resistance to RNA-type viruses (such as YHV in Asia, and TSV in Latin America) in Penaeid shrimp (Flegel *et al.*, 1977).

It is known that YHV occurs in wild shrimp, but there is no data on the extent or effects of YHV on populations of wild shrimp in Asia and its impacts are thus currently unknown.

The primary mechanism of spread of YHV in pond culture appears to be from water and mechanical means or from infected crustacean carriers (Flegel *et al.*, 1995 and 1997). Some infected carriers appear to have latent infections (*i.e. P. merguiensis*, *Metapenaeus ensis*, *Palaemon styliferus* and *Acetes spp*.), while others may die from it (*i.e. Euphausia superba*). Other crustaceans, such as *Macrobrachium rosenbergii* and many crab species and *Artemia* appear unsusceptible (Flegel *et al.*, 1997).

Since, like most viruses, the viability of the free virus in seawater is not more than a couple of hours, the most serious threat to farmers is latent or asymptomatic carriers, from which the virus can be spread either by ingestion or cohabitation. In addition, infected broodstock can pass on the virus to larvae in the maturation/hatchery facilities if thorough disinfection protocols are not strictly adhered to (Flegel *et al.*, 1997).

Although a distinct possibility, YHV has not yet been reported from Latin America apart from some probably spurious results from Texas in 1995 (Lightner, 1996). However, from work in Hawaii, YHV is known to cause high mortality in *P. vannamei*, *P. stylirostris*, *P. setiferus*, *P. aztecus* and *P. duorarum* when it is injected as viral extracts (Lu *et al.*, 1994; Lightner, 1996). Despite this, there are still no reports of "natural" infections in shrimp farms of *P. vannamei* and *P. stylirostris* with YHV in Asia. There is a strong possibility, however, that YHV may cause problems for the new culture industries for *P. vannamei* and *P. stylirostris* in Asia. This will probably be true at least until these species can gain some degree of tolerance or resistance to the virus as *P. monodon* appears to have done. In the meantime, the large number of latent infected hosts (including *P. monodon*) will serve as a potential reservoir of infection and should not be permitted to come into contact with cultures of *P. vannamei* or *P. stylirostris*.

YHV principally affects pond reared *P. monodon* in juvenile stages from 5-15 g (Lightner, 1996). Shrimp typically feed voraciously for two to three days and then stop feeding abruptly and are seen swimming near the pond banks. YHV infections can cause swollen and light yellow coloured hepatopancreas in infected shrimp, and a general pale appearance, before dying within a few hours. Total mortality of the crop is then typically seen within three days. Experimentally infected shrimp develop the same signs as those naturally infected, indications of the disease are noted after two days and 100 percent mortality results after three to nine days (Lu *et al.*, 1995; GSMFC website).

Yellow head virus can be detected by RT-PCR or with a new probe for dot-blot and *in situ* hybridisation tests. It can also be diagnosed histologically in moribund shrimp by the presence of intensely basophilic inclusions, most easily in H&E-stained sectioned stomach or gill tissue, or simply by rapid fixation and staining of gill tissue and microscopic examination. Exact protocols for all of these techniques are given in the OIE website and by Flegel *et al.* (1997).

Eradication methods in ponds are much the same as for other viruses and involve a package including: pond preparation by disinfection and elimination of carriers, storage and/or disinfection of water for exchange with chlorine (30 ppm active ingredient), filtering water inlet to ponds with fine screens, avoidance of fresh feeds, maintenance of stable environmental conditions, disinfection of YHV infected ponds before discharge, and monitoring (by PCR) and production of virus free broodstock and PL for pond stocking (Flegel *et al.*, 1997). Various immunostimulants, nutrient supplements and probiotics have been tried, but there remains a paucity of conclusive evidence of the benefits of such treatments.

The rapid tolerance gained by *P. monodon* to YHV provoked theories as to its mechanism (Pasharawipas *et al.*, 1997). Whether this theory is correct or not, field data has indicated that shrimp surviving a YHV epidemic are already infected and thus are not killed by subsequent infections, suggesting that some type of "vaccination" (Flegel *et al*., 1997) with a dead or attenuated virus might provide some resistance. Some commercial products are already being marketed and trials have been partially successful. YHV is not causing much loss at present in Asia, but general management practices as described above (to maintain optimal environmental conditions and minimize viral loadings) are still required to help prevent infections (Flegel *et al.*, 1997).

Lymphoid Organ Vacuolization Virus (LOVV)

Lymphoid Organ Vacuolization Virus was first noted in *P. vannamei* farms in the Americas in the early 1990s (Brock and Main, 1994). In *P. vannamei*, LOVV has been shown to result in limited localized necrosis of lymphoid organ cells, but has never been shown to impact production. It was later discovered in Australia, along with the other TSV-like virus GAV (Lightner and Redman, 1998b).

Due to the coincidence in dates, it is possible that the main cause of the problems with *P. monodon*, was a result of the introduction of viral pathogens carried by *P. vannamei*. A RNA viral pathogen very similar to LOVV in *P. vannamei* has recently been discovered in Thailand in the lymphoid organ of *P. monodon* (December 2002, by D.V. Lightner). This new type of LOVV might be the causative agent of this slow growth phenomenon. Evidence for this was provided by Timothy Flegel (per. com.), who found that juvenile *P. monodon* injected with this virus grew to only 4 g after two months, whilst those injected with a placebo reached 8 g in the same time. Injections of the same virus into *P. vannamei* caused no obvious effects, suggesting that it probably originated from this species.

Other viruses

There are a number of other viruses in the Asia-Pacific region. *Penaeus monodon* from Australia have been found to be hosts for a number of viruses not yet present in other Asian countries. These include two viruses closely related to YHV: GAV (only 20 percent genetically different to YHV) and MOV (only 10 percent genetically different from GAV), which are quite recently discovered viruses that are already prevalent in 100 percent of *P. monodon* from Queensland (Timothy Flegel, per. com.). MOV was only discovered in 1996, but has already been found in *P. japonicus* and is associated with disease episodes in *P. monodon* farms in Australia and elsewhere in Asia (IQ2000 website[21]). The strong possibility for the introduction of these viruses into Asia exists due to frequent shipments of *P. monodon* broodstock from Australia into Thailand, Viet Nam and other Southeast Asian countries.

Many of the viruses infecting shrimp are hidden or cryptic and, although present in their host, may produce no gross signs of disease or notable mortality. Many of these viruses, without methods of diagnosis, are probably being harboured unknown within the wild and cultured populations of shrimp throughout the world. It may not be until shrimp species from one location are moved to another and their viral flora comes into contact with new and/or naive or intolerant hosts that disease epidemics begin. Crustaceans may be particularly problematic since they tend to have persistent, often multiple, viral infections without gross or even histological signs of disease (Flegel and Fegan, 2002).

Examples of this problem include the transfer of IHHNV from the tolerant *P. monodon* in Asia to the susceptible white shrimp *P. vannamei* and *P. stylirostris* in Latin America. Another possibility in this category is the LOVV virus thought to be causing the slow growth phenomenon in *P. monodon* around Asia. This virus may have been imported with live *P. vannamei* broodstock and PL brought to Asia from the Americas in the mid-1990s. For this reason, extreme caution should be placed on the transboundary movements of live shrimp.

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[21] http://www.iq2000kit.com/

6.5 Other diseases

Necrotizing hepatopancreatitis (NHP)

Necrotizing hepatopancreatitis is caused by a Rickettsia-like intracellular bacterium and has been an important disease in Texan shrimp culture since its first diagnosis in 1985. It has resulted in mass mortalities (20-90 percent) of *P. vannamei* in highly saline commercial grow-out ponds nearly every year since then (Thompson *et al.*, 1997). By 1993, NHP had spread to Ecuador and Peru, and by 1995, coinciding with warm waters with high salinity associated with El Niño, was causing severe mortalities (60-80 percent mortality) of *P. vannamei* and *P. stylirostris* throughout Ecuador (Jiménez *et al.*, 1997). It is believed that NHP was spread with infected PL from Central America to Peru and Ecuador (Jiménez *et al.*, 1997).

NHP has not yet been reported in Asia, but could cause significant damage were it to be transferred here with untested shrimp from Latin America (Fegan, 2002).

6.6 Known and suspected impacts of viral disease

Endemic viruses affecting shrimp culture and capture fisheries

There are few rigorous analyses of the costs of disease on aquacultural and capture fishery activities. Most of the estimates that have been made were based on the estimated value of production which was presumed lost due to disease with reference to national production figures pre and post-epidemic. For shrimp culture, "native" viruses causing problems have been largely due to WSSV and YHV in Asia and TSV and IHHNV in Latin America.

Estimates for Asia include: a loss of over US$ 250 million for 1993 (continuing every year) in Mainland China, loosing 120 000 metric tonnes of production of *P. chinensis*, *P. japonicus* and *P. monodon* to WSSV (Jiang, 2000); US$ 400 million in direct economic loss due to all shrimp diseases in 2002 (Chen Aiping, per. com.); US$ 300 million since 1992 for lost production in Indonesia due to YHV and WSSV (Rukyani, 2000); US$ 30-40 million/year due to YHV in 1992 and 1993, rising to 240-650 million/year between 1994 and 1997 due to WSSV and THV in Thailand (Chanratchakool *et al.*, 2000); US$ 100 million in 1993 due to WSSV, YHV and MBV in Viet Nam (Khoa *et al.*, 2000); US$ 25 million/year due to WSSV in Malaysia (Yang *et al.*, 2000); Rp4-5 thousand million annually in India to WSSV and YHV (Mohan and Basavarajappa, 2000); up to Rp1 thousand million per year since 1996 in Sri Lanka to WSSV and YHV; and US$ 32.5 million between 1994-1998 in Australia due to "Mid Crop Mortality Syndrome" (MCMS)(Walker, 2000).

Total losses in Asia over the past decade may thus reach close to US$ one thousand million/year due to the direct effects of "native" viruses on shrimp production. However, none of these figures takes into account ancillary industry losses including: unemployment and social upheaval (see Section 9.5.5), reduced requirements for feed, chemicals and other supplies, closure of hatcheries and capture fisheries for broodstock and wild seed, reduced requirements for packing, processing, export and shipment of shrimp produced, reduced investor confidence and so on.

Latin American shrimp farmers have also suffered huge economic and social problems related to outbreaks of native viral disease epidemics, especially TSV and IHHNV since 1993 (Figure 2). For example, Ecuador lost up to US$ 400 million per year from 1992 to 1997 to TSV (Lightner, 1996a); Honduras lost 18, 31 and 25 percent of its shrimp due to TSV in 1994, 1995 and 1996 respectively (Corrales *et al.*, 2000); Panama lost 30 percent of its production to TSV in 1996 (Morales *et al.*, 2000); Peru lost US$ 2.5 million to TSV in 1993 (Talavera and Vargas, 2000); and Mexico lost US$ 25 million due to IHHNV infections in *P. stylirostris* in the late 1980s/early 1990s (SEMERNAP, 2000). It has been suggested that TSV caused direct losses (due to shrimp mortality) of US$ 1-1.3 thousand million in the first three years in

Latin America. However, as in Asia, indirect losses due to loss of sales, increased seed costs and restrictions on regional trade were probably much higher (Brock *et al.*, 1997; Hernandez-Rodriguez *et al.*, 2001).

Introduced shrimp affected by native viruses

To date, in Asia, the introduction of infected broodstock of *P. vannamei* from Latin America from 1996 onwards is known to have resulted in the introduction of TSV into Mainland China and Taiwan Province of China (from 1999). TSV is now believed to be causing mass mortalities in cultured *P. vannamei* in both countries (Tu *et al.*, 1999; Yu and Song, 2000; Chen Aiping, per. com.). Estimates of the economic and social losses have not yet been made. TSV is also now known to be present in Thailand and is reported to be beginning to cause heavy mortalities to the *P. vannamei* being cultured there (Timothy Flegel, per. com.).

In Latin America, although *P. monodon* and *P. japonicus* have been imported at various times, their culture has never been successful, so that losses of these species due to the diseases brought with them have never reached a high level of economic significance.

Native cultured shrimp affected by alien viruses

Introduced WSSV has resulted in significant loss of production of Penaeid shrimp in Latin America since 1999. In Ecuador for example, within the first year of the WSSV epidemic in 1999, the disease caused a direct financial loss of US$ 280 million (42 percent of production capacity, or 63 000 metric tonnes of *P. vannamei* and *P. stylirostris*) (Alday de Graindorge and Griffith, 2000). Data from the CNA of Ecuador suggest a direct loss of US$ 1.7 thousand million between 1999 and the first half of 2003 (CNA website, Figure 2). Other problems resulting from the WSSV epidemic have been seen in Honduras (13 percent reduction in workforce) (Corrales *et al.*, 2000), and 40 percent (4 400 metric tonnes) of lost production worth US$ 40 million in 1999 in Panama with *P. vannamei* (Morales *et al.*, 2000). Every other Latin American country, with the exception of Brazil and Venezuela, including USA, had also suffered serious problems due to WSSV since 1999.

No problems have yet been encountered with TSV infecting native cultured shrimp species (*i.e. P. monodon*) in Asia, although *P. monodon* and *P. japonicus* appear to be largely refractory to TSV (Brock *et al.*, 1995). *Penaeus chinensis* (and others) have been experimentally infected with TSV (Overstreet *et al.*, 1997). Together with the mutative capacity of RNA viruses like TSV, this illustrates the potential for infection of native species and is a major cause for concern.

Wild shrimp populations affected by alien viruses

It has been reported that pathologic viruses could be transmitted to native wild Penaeid shrimp populations (Overstreet *et al.*, 1997; Joint Sub-committee on Aquaculture (JSA.), 1997), thus introduced alien shrimp viruses may be capable of infecting native wild shrimp populations.

Taura Syndrome Virus has been detected in wild *P. vannamei* escapees in the United States, but appears to have had minimal impact on wild shrimp populations (Brock, 1997; GMFS website; OIE website). Taura Syndrome Virus appears to occur largely as a sub-clinical infection in populations of wild shrimp (Brock *et al.*, 1997).

There is some evidence of TSV in the wild populations of *P. monodon* around the southwest coast of Taiwan Province of China during 2000, although pathological effects on its new host were not noted and they appear largely unaffected (IQ2000 website). *Penaeus japonicus* is also known to be refractory to TSV, but the effects of TSV on native stocks of wild Asian *P. indicus* and *P. merguiensis* are not known and are a definite cause for concern. This is especially worrying since TSV is a highly mutable RNA virus and could mutate into a more virulent form for native Asian shrimp, as it has done in Latin America (Flegel and Fegan, 2002; Lightner, 2002).

There are speculations that IHHNV originating from United States culture facilities may have caused the closure of the Mexican shrimp fishery from 1987 to 1994 and the loss of millions of dollars, since wild *P. stylirostris* (and other less prevalent native species) proved highly susceptible to IHHNV (Lightner, 1996b; JSA, 1997). IHHNV is commonly found in wild shrimp on the Pacific coast of Latin America and throughout Asia, from where it probably originated (OIE website; Lightner, 2002). In Asia, IHHNV is not thought to cause many problems, since *P. monodon*, *P. indicus* and *P. merguiensis* are all refractory to the disease, having spent a long time cohabitating with it (Flegel and Fegan, 2002).

Since WSSV was first reported in the USA in 1995, it has been found in cultured and wild shrimp, crabs and freshwater crayfish at multiple sites in the eastern and south-eastern United States including Texas (Lightner, 1999). WSSV-positive shrimps and crabs have been found regularly in Texas from 1998, although the effects of WSSV on these wild populations remain unquantified (APHIS website). Despite the fact that WSSV was reported as eradicated from shrimp farms in the United States in 1997, it is still found in wild stocks in the Gulf of Mexico and the southeast Atlantic states and so is probably now established (Lightner, 2002).

WSSV is also found in wild shrimp throughout Asia, but again, its effects on the wild stock remain unclear. However, since WSSV is easily passed from spawners to their larvae (if the eggs and nauplius are not thoroughly disinfected), its effects in the wild population could be greatly affecting the Asian *P. monodon* culture industry.

Similarly, LOVV was found in wild spawners from the Andaman Sea off Thailand by Donald Lightner in 2002. It is thought that this virus might be the cause of the slow-growth phenomenon currently affecting cultured *P. monodon* in Asia (Timothy Flegel, per. com.), and if so, it is having a huge economic impact on the Asian shrimp culture industry.

Socio-economic costs of shrimp viral diseases

In addition to direct effects on production, the impacts of diseases are particularly felt by small-scale farmers who, especially in Asia, represent the backbone of many coastal communities. Their very livelihoods are threatened through reduced food availability, loss of income and employment, social upheaval and increased vulnerability. Crop losses to disease for this sector of society may determine whether or not those families are below the UN poverty threshold (Fegan *et al.*, 2001). In Mainland China, for example, the WSSV epidemic in 1993 affected the lives of 1 million people, and has continued to have effects to this day (Jiang, 2000).

Similar effects have been noted from Latin American countries. In Ecuador for example, within the first year of the WSSV epidemic in 1999, the disease also lead to the loss of 26 000 jobs (13 percent of the labour force), the closure of 74 percent of the hatcheries, a 68 percent reduction in sales and production for feed mills and packing plants, 64 percent layoffs at feed mills and a total of 150 000 jobs lost in the shrimp farming industry (Alday de Graindorge and Griffith, 2000). Although production has been slowly increasing since then, the Ecuadorian industry remains at less than 45 percent of its maximum in 1998 prior to the WSSV epidemic, effectively putting production levels back 16 years, to those achieved in 1987 (Figure 2).

7. International and national efforts in controlling alien species movement

Problems encountered with the introduction or movement of shrimp have recently become a major issue in world shrimp farming. This is particularly the case for introduction of non-indigenous species into new countries. The broad ecological risks and impacts of transboundary movements and introductions of shrimp are still poorly understood, but have to date centred on the unwitting introduction of pathogens/disease (particularly viruses) together with their shrimp hosts. These viruses have the demonstrated ability to spread rapidly through movements of live shrimp and cause serious losses to cultured and wild shrimp populations and severe socio-economic losses to the inhabitants of the countries involved.

Shrimp are particularly susceptible to viral pathogens since they are characterized by persistent viral infections which often produce no gross signs of disease or mortality, which may be unknown and/or difficult to detect, and which can cause severe losses of cultured and wild hosts, once they are unwittingly introduced. Shrimp may also be host to multiple viruses which may be tolerated in one host species or location, but which may cause serious problems in another.

Another problem is that the relative risks of viral transfer through many possible routes of infection remain largely unknown. Introductions of live PL and/or broodstock have been strongly implicated in the majority of cases, whilst frozen shrimp, although often infected, appears to be an unlikely source and are easier to control (Flegel and Fegan, 2002).

Additionally, there are also poorly researched and understood issues dealing with potential loss of biodiversity, the effects of escapes of alien shrimp and pathogens to the wild stocks, marketing issues and the triggering of trade barriers. These issues are discussed in sections 6.2 and 5.3.

These potential problems have resulted in many countries implementing bans or restrictions on the importation of live shrimp (and in some cases frozen shrimp) and in some cases other potential disease vectors such as fresh feeds. There has been much concern regarding the basis and implementation of these bans related to international trade agreements and difficulties in enforcing such limitations.

7.1 International and regional organizations and their relevance to shrimp trade

World Trade Organization (WTO)

International trade issues are governed by the World Trade Organization (WTO), the legal and institutional basis for the international trading system. The main objectives of the WTO agreement were to ensure access to markets, promote fair competition and encourage development and economic reform. Aquacultural issues are covered specifically in the "Agreement on the Application of Sanitary and Phytosanitary Measures" (SPS, 1995) and the "Agreement on Technical Barriers to Trade" (TBT).

The SPS agreement attempts to prevent non-tariff trade barriers based on harmonized international standards, guidelines or recommendations where they exist. However, individual governments may take more stringent measures, over and above the guidelines provided by the standard setting authorities (in the case of animal health it is the World Organisation for Animal Health – OIE), provided they have scientific justification (*i.e.* following an import risk assessment), or if it is shown that international standards do not provide sufficient risk protection. Problems with harmonization of standards may arise if, for example, an importing country refuses permission to import a product from a country with a new or a viral disease listed in the OIE Aquatic Animal Health Code (OIE, 2003) list of viral diseases and the exporting country does not have the mechanism to ensure the product is free from the virus. Under these circumstances, the WTO has agreed to assist developing countries in building their capacities and improving their standards. Settlement of disputes bilaterally is encouraged, but the WTO has its own procedures and impartial bodies are available if this is not possible (Fegan, 2000).

World Organisation for Animal Health (OIE)

The Paris-based World Organisation for Animal Health (OIE) sets the international standards for animal health measures. Since 1988, it has been involved in developing standards for aquatic animal health, through the Aquatic Animal Health Standards Commission (AAHSD). The OIE is responsible for informing governments of the worldwide aquatic disease situation, coordinating possible surveillance and control measures and harmonizing regulations for trade amongst member countries. The OIE regularly updates the two important documents for aquatic animal health: the Aquatic Animal Health Code (OIE, 2003a) and the Manual of Diagnostic Tests for Aquatic Animals (OIE, 2003b), which are available on the OIE website at http://www.oie.int.

International Council for the Exploration of the Sea (ICES)

A code of practice for introductions of non-indigenous marine organisms was set by the International Council for the Exploration of the Sea (ICES) in 1973 and revised in 1994 (ICES, 1995). These codes had recommendations in the following areas: recommended procedures for deciding on importations of new species; recommended actions once the introduction has been approved; encouragement for prevention of unauthorised introductions; and recommended procedures for introduced or transferred species already under commercial cultivation.

Food and Agriculture Organization of the United Nations (FAO)

Member states of FAO adopted a voluntary Code of Conduct for Responsible Fisheries (CCRF) during the FAO Conference of 1995 (FAO, 1995). The CCRF was the result of four years of work following the International Conference on Responsible Fishing in Cancun, Mexico in May 1992. Although voluntary, the provisions of this Code are increasingly included in national legislature and regulatory frameworks, which indicates the national interest in compliance.

Article 9 of the code is on Aquaculture development and Article 9.3.3 states that: "States should, in order to minimize risks of disease transfer and other adverse effects on wild and cultured stocks, encourage adoption of appropriate practices in the genetic improvement of broodstock, the introduction of non-native species, and in the production, sale and transport of eggs, larvae or fry, broodstock or other live materials. States should facilitate the preparation and implementation of appropriate national codes of practice and procedures to this effect".

FAO further issued the "FAO Technical Guidelines for Responsible Fisheries No. 5: Aquaculture Development" in 1997 to provide general advice in support of Article 9 of the CCRF (FAO, 1997).

Asian Regional Initiatives (FAO/NACA/SEAFDEC/ASEAN)

Based on Article 9.3.3 of the FAO CCRF, a set of regional guidelines were issued by FAO/NACA in 2000 called the "Asia Regional Guidelines on Health Considerations for the Responsible Movement of Live Aquatic Animals". These guidelines were developed through three years of awareness raising and consensus building and were adopted by 21 participating countries in the Asia-Pacific region in Beijing in June 2000. The guidelines were adopted by the ASEAN Fisheries Working Group in Bali in 2001 as an ASEAN (Association of South East Asian Nations) policy document and endorsed by the ASEAN/SEAFDEC (Southeast Asian Fisheries Development Centre) Millennium Conference on Fish for People in 2000 in Bangkok (FAO, 2000; NACA/FAO, 2001; SEAFDEC, 2001).

7.2 Selected national initiatives relevant to movement of shrimp species

United States of America

The USA has had a long history of introductions of transboundary shrimp species, including *P. vannamei*, *P. stylirostris*, *P. monodon*, and *P. japonicus*, amongst others. With the importation of these species from all over the world, non-indigenous and highly pathogenic viral diseases also entered the cultured and wild stocks of Penaeid shrimp.

For example, IHHNV was introduced to Hawaii with infected *P. monodon* from Asia (probably the Philippines) in 1981 (Tang *et al.*, 2002). The TSV spread from South (1992) and Central (1994) America to arrive in the USA in Florida in 1994 and Texas and Hawaii in 1995 (Brock *et al.*, 1997). In addition, WSSV arrived in Texas in 1995, at the time this was attributed to imports of frozen *P. monodon* from Asia, although this is still speculation (Lightner, 1996) (Section 6.3).

In 1988, the US Environmental Protection Agency (EPA) and the Joint Sub-committee on Aquaculture (JSA) (as a facilitator among the various agencies involved with aquaculture) held a *Review and Risk Assessment Workshop* to conduct a qualitative assessment of the risks associated with shrimp viruses, to evaluate the need for a more comprehensive risk assessment and to identify research needs. Results were passed to state management agencies to help develop regulatory mechanisms for the potential impacts of viral transmission to indigenous populations (Olin, 2001).

Further recommendations were made during the workshop held in 1996 by the specially organized Shrimp Virus Work Group of the JSA. The workshop was aimed at developing an interagency strategy to address the shrimp virus issue, beginning with an assessment of the effects on wild shrimp populations, and initiating the development of a risk assessment to determine actions aimed at averting further viral introductions (JSA, 1997). The viral risk assessment report arising from this was presented at the EPA/JSA Viral Assessment Workshop held in 1998, and concluded that more research is necessary to fully identify the risks of shrimp viruses on wild populations (US Environmental Protection Agency website[22]).

In addition, the "Lacey Act" was formulated to help restrict the movement of named potential pathogens into the United States and into watersheds where the pathogen is not currently found. This act is overseen by the US Department of the Interior, Fish and Wildlife Service and is backed by individual state legislation according to needs and diagnostic assistance from USDA's Animal and Plant Health Inspection Service (APHIS) (US Congress, Office of Technology Assessment, 1996).

Due to the privileged position of Hawaii as being very isolated from most shrimp culture operations and the abundance of clean, essentially virus-free water, it was designated as a broodstock production area, concentrating on genetic improvement and health management (biosecurity), with funding from the USDA. From the late 1980s, the USDA Marine Shrimp Farming Program (MSFP) began the establishment of SPF lines of *P. vannamei* using the facilities of the Oceanic Institute in Hawaii (with assistance from the Waddell Mariculture Center, the Gulf Coast Research Laboratory and the University of Arizona Department of Medical Science). These SPF lines have subsequently been used by many commercial and government-run broodstock facilities in Hawaii (and Florida). The USA biosecurity strategy arising from deliberations of the USDA MSFP was published as *Proceedings of the US Marine Shrimp Farming Biosecurity Workshop* in 1988 (Moss, 1988). This document contains many of the regional criteria developed and implemented subsequently by the United States involving shrimp movements.

The broodstock facilities in Hawaii were cleared of their infected stocks and restocked with screened and quarantined stocks of various species from around the world which were confirmed as virus-free over a long period through multiple checking by PCR, according to the MSFP biosecurity code. These

[22] http://www.epa.gov/

Hawaiian facilities then started producing SPF and SPF/SPR (mainly for TSV and IHHNV) stocks of *P. vannamei* (and also *P. stylirostris*, *P. monodon* and *P. japonicus*) for distribution to United States and worldwide production facilities. In 2004, however, WSSV was detected and reported in shrimp in Hawaii despite these stringent measures.

Broodstock of these SPF *P. vannamei* and *P. stylirostris* have been extensively introduced to Asia. The aim of these initiatives was to reduce dependence on imported shrimp (and thereby attendant viruses) by supporting the local industry, whilst reducing the national trade deficit (Olin, 2001). They have also, however, enabled Asian and other countries to have access to disease-free founder populations of various species with which to start their own industries. This is a new innovation in world shrimp farming, but unfortunately has not often been implemented with sufficient care to take full advantage of its benefits.

Ecuador and Mexico

Several Central and South American countries immediately closed their borders to the importation of live, fresh and frozen shrimp after the introduction of WSSV to the region in 1999 from unknown sources. Most of those countries imposed new regulations in late 1999 *(i.e.* Mexico) or 2000 (*i.e.* Ecuador), which typically included specifying imports of only SPF stocks from certified, tested and enclosed facilities to certified and controlled facilities with quarantines in the respective countries. They also insisted on PCR testing of all imported material for WSSV and YHV. These regulations typically persist until today.

The WSSV episode in Latin America, however, caused major disruptions in the trade of shrimp within the region, particularly to live shrimp exporters – nauplii and PL suppliers in particular, which suddenly found their main markets closed to them. Fortunately for most of these countries, these problems gave the final incentive for the intensification of efforts to close the cycle and develop domesticated and selected SPR lines of *P. vannamei* and *P. stylirostris*. They were thus able to satisfy their own demands through the development of these lines, with the help of which the industry has managed to recover slightly over the ensuing three to four years.

Brazil

Brazil began importing non-indigenous shrimp in 1980 and *P. vannamei* and *P. stylirostris* in 1983 from all over Latin America. This resulted in the introduction of various viral diseases including IHHNV, TSV and NHP. By 1998 the Brazilians began to invest more in captive breeding programmes for *P. vannamei* and therefore, once WSSV arrived in Latin America in 1999, Brazil immediately closed its borders to imports of live, fresh or frozen crustaceans (including Artemia) and polychaete worms (De Barros Guerrelhas, 2003). To date, the restriction has been successful, and Brazil remains free from WSSV and YHV. Because of this and successful genetic selection programmes (*i.e.* for TSV-resistant strains), Brazil has increased its production over 12-fold since 1998 to the present reaching 60 000 metric tonnes in 2002 and an estimated 90 000 metric tonnes in 2003 (De Paiva Rocha, 2003).

Pacific Islands

Both *P. vannamei* and *P. stylirostris*, along with many other Penaeid shrimp species, were imported to New Caledonia and French Polynesia in the 1970s, before many of the current viral diseases were known. They were all held in quarantine and proven free of diseases before being released for culture. The Pacific Islands are thus free of all major viral diseases currently recognized.

Stocks of most of these species still exist, so that subsequent importations have thus slowed considerably. Fiji has instituted an Animal Act regulating importations of alien species and New Caledonia has regulations that are self-imposed by producers cooperatives aimed at preventing the introduction of viral diseases (Ben Ponia, per. com.).

Thailand

Thailand began importing *P. vannamei* in 1998 from diverse (non SPF) sources, but its commercial culture remained mostly experimental until 2001 when problems with a decrease in the growth rate of *P. monodon* encouraged farmers to search for alternatives. The possibility that this problem was actually caused by viruses brought in with *P. vannamei* is discussed in Section 6.3.

Although not officially permitted, farmers then began importing large numbers of broodstock and PL from Mainland China and Taiwan Province of China, and lobbying the government to allow *P. vannamei* importations. Due to these pressures the Thai government carried out a risk assessment regarding the possibility of interbreeding with native species and then finally allowed official importations of certified SPF broodstock only from March until the end of August 2002, but only to qualified and audited hatcheries with restrictions. At this time the first SPF broodstock were imported from Hawaii.

Due to increasing concerns about the smuggling of non-SPF *P. vannamei* from Mainland China and Taiwan Province of China to uncertified hatcheries, and the first signs of TSV in Thai *P. vannamei* and *M. rosenbergii* (Flegel, 2003), the Department of Fisheries then closed the border to all imports again in early 2003, and it remains officially closed to this date (April, 2004). However, due to the huge demand for PL, large quantities of *P. vannamei* from within Asia and from the Americas were still being smuggled into Thailand, despite the official ban. The Thai Department of Fisheries is currently considering what action, if any, to take regarding the importation of *P. vannamei*. Despite the importation ban, Thailand produced 10 000 metric tonnes of *P. vannamei* in 2002 and was expected to produce 120 000 metric tonnes in 2003, which would constitute nearly 40 percent of its total shrimp production (Table 3).

Malaysia

Malaysia implemented an indefinite ban on introduction of *P. vannamei*, operative from the 1 June 2003, in an effort to prevent the introduction of TSV and other viruses to Malaysia (The Wave website, 2 April 2003). This ban was late in coming since *P. vannamei* was imported into Peninsular Malaysia from Taiwan Province of China in 2001 and Thailand in 2002, and also to one farm in Sabah. However, these introductions were not technically illegal since Malaysia previously only had restrictions on certain named species, not including *P. vannamei* or *P. stylirostris*.

A continuing lack of information and education of the local farming community on the potential risks of *P. vannamei* farming, together with the absence of a system for monitoring the importation and farming of alien species in Malaysia, has resulted in limited impact on dissuading farmers from importing this species.

Malaysian farmers have already adopted the culture *P. vannamei* due to numerous perceived benefits, not least the mistaken idea that *P. vannamei* is resistant to WSSV. Malaysia already increased its production to 1 200 metric tonnes/year by 2002, with the potential to triple this in 2003 (Table 3). Despite importation of non-SPF stocks, in contravention of the ban, there are still no reports of TSV from Malaysia. Without strict enforcement, however, currently successful farmers could resort to illegal imports in order to maintain their production, which will inevitably bring TSV to Malaysia, if it is not already present.

The State of Sarawak has no *P. vannamei* farms since they have to obtain licenses from the Malaysian government to operate their farms and are concerned that these licenses could be revoked and their ponds destroyed if they are caught farming *P. vannamei* (Dato Mohamed Shariff, per. com.).

Registration of all farms culturing *P. vannamei* with the Department of Fisheries could permit a comprehensive monitoring programme and risk assessment to be undertaken to help ensure that practical, longer-term legislation could be introduced to help management of imported alien species and limit disease transmission (Dato Mohamed Shariff, per. com.).

The Philippines

The Philippines began legislation for shrimp importation at the height of the WSSV epidemic in Asia in 1993 to prevent the introduction and spread of alien disease agents. The Bureau of Fisheries and Aquatic Resources (BFAR) immediately implemented a ban on the importation of all live shrimp and prawn species of all stages except for scientific or educational purposes. Such importations required permission from the Secretary of Agriculture and a demonstrated capacity for biosecurity according to ICES and BFAR (import risk analysis panel) recommendations (Fred Yap, per. com.).

The first importation of *P. vannamei* was made before this law was passed in 1978, but was unsuccessful and the shrimp were all harvested and consumed. Despite private sector lobbying to lift the import ban, the fishery agency refused to approve any applications. The private sector then began illegal importation of *P. vannamei* due to disease problems with the culture of *P. monodon*. These illegal importations began in 1997 and comprised PL originating from Taiwan Province of China, labelled as milkfish fry to circumvent the importation law.

In 2001, due to these violations of the law, the Philippine government issued a new law to include prohibition of culturing imported shrimp and penalties for violations comprising a fine of up to US$ 1 500 and up to eight years in jail.

Subsequent high profile confiscations of illegally imported shrimp fry from Taiwan Province of China occurred in 2002 and 2003 and restrictions to limit all live fish imports to just one airport were applied to further strengthen the control over illegal importations. However, these regulations are known to have resulted in the dumping of PL *P. vannamei* into the wild in attempts to escape detection (Timothy Flegel, per. com.). Additionally, typhoons have also resulted in the liberation of *P. vannamei* from culture ponds into the surrounding sea. A population of *P. vannamei* in the wild therefore already exists in the Philippines, although it is still uncertain if this population is now breeding (Fred Yap, per. com.).

Plans to allow importation of only SPF *P. vannamei* broodstock and their subsequent sale only after reaching the F1 generation and confirmation of disease-free status were originally approved by the BFAR (Bureau of Fisheries and Aquatic resources), but later rescinded due to suspicions that the company requesting the importation permit was already producing PL *P. vannamei* for sale.

Despite all of the efforts of the BFAR, the culture industry for *P. vannamei* in the Philippines is growing and may produce as much as 5 000 metric tonnes in 2003 (Table 3). In addition, once pond reared broodstock become available the farmers will no longer have to rely on imports of PL or broodstock to maintain production. Although the culture of *P. vannamei* remains illegal, the ban is difficult to enforce (particularly since it is clearly now present in the country), and there are members of the government who are in favour of controlled importations of SPF animals. Legislation to allow this already exists and it may be the only way to ensure importation of disease-free stocks to the industry that is being driven by market forces despite official restrictions.

Viet Nam

Viet Nam has had an official ban on the culture of *P. vannamei* since June 2002, but some importations and culture have been permitted. They are currently conducting culture tests with this species in (supposedly) biosecure facilities in order to evaluate its positive and possibly negative impacts. In order to conduct these trials, since 2001, the Ministry of Fisheries (MOFI) has granted nine licenses to commercial companies, permitting the importation of up to 48.5 million PL and 5 900 broodstock *P. vannamei*. These animals originated from the USA (Hawaii) and China, and are inspected by MOFI to ensure that they are disease-free before allowing their culture. However, current inspection protocols do not appear to be capable of definitively proving the disease status of the imported stocks (FAO correspondent, Viet Nam).

The PL imported or produced by these companies may be either cultured by these companies or sold to third parties to culture (after being given permission by MOFI). Of the nine companies, only one to date has passed the trial period and is officially allowed to disseminate its products for culture, and even then only within the Mekong river delta (FAO correspondent, Viet Nam).

However, while these quotas remain unfilled and open, *P. vannamei* appeared to be cultured in North Viet Nam using PL illegally imported from Mainland China. Additionally, it has been estimated that during the first six months of 2003 alone, two thousand million PL were imported from Mainland China for culture within Viet Nam (FAO correspondent, Viet Nam).

Despite official restrictions, it is estimated that approximately 10 percent of the countries' 479 000 ha of shrimp ponds are now being used to culture *P. vannamei*. This is driven by the scarcity and high price of PL *P. monodon*, together with the low cost of mostly Chinese PL and the good results obtained in grow-out. The result is that Viet Nam's estimated production in 2003 was 30 000 metric tonnes (FAO correspondent).

Indonesia

Indonesia has recently enacted a decree permitting imports of shrimp, including *P. vannamei* provided that the purpose is justified and an import certificate or a licence to import is obtained from the relevant national authorities. Importation from Taiwan Province of China is not permitted. It is certain that *P. vannamei* is present in Indonesia and there have been outbreaks of TSV in the country (Akhmed Rukyani, per. com.). It is suspected that TSV first occurred in Banyuwangi and Situbondo before spreading to other districts in East Java through movement of infected post larvae. Banyuwangi and Situbondo are two of Indonesia's shrimp (*P. monodon* and *P. vannamei*) production centres, producing both seed and marketable shrimp. Samples of *P. monodon* originating from Brebes (Central Java), Situbondo (East Java) and Bali islands have also been found to be PCR positive against TSV. TSV has also been found in *P. vannamei* from Maros (Sulawesi islands) and Sumbawa islands. All of the samples were confirmed by PCR-based methods (Agus Sunarto, per. com.)

India

Until recently, the only legislation relating to the importation of live animals into India was the 1898 Livestock Importation Act. However, this was neither designed nor effective in controlling importation of aquatic animals. Thus from 2001, the Department of Animal Husbandry and Dairying of the Ministry of Agriculture took responsibility for issuing (based on advice from the National Committee on Exotics) a Sanitary Import Permit, which must accompany any importation of fishery products. Subsequently, the Marine Products Export Development Agency (MPEDA) issued a public notice specifically warning against the illegal aquaculture of *P. vannamei*, with some success.

The first imports of *P. vannamei* were made prior to the recent legislation, with two farms importing PCR-tested SPF broodstock from Hawaii via Taiwan Province of China in 2001. Subsequently, two more farms were granted permission by the government to import SPF broodstock, with provisions made for ensuring biosecurity from a specially appointed committee. These farms are being used to test the culture potential and risks involved with farming *P. vannamei* before any further measures are taken by the government. Other than these, there appear to have been no further introductions, suggesting that India may still be free of the viruses carried in with imported *P. vannamei* elsewhere in Asia.

Nonetheless, the initial successes of culturing *P. vannamei* have led to the more widespread culture of the species in India using locally reared broodstock. It is estimated that there now exist 3 hatcheries and 37 farms covering 120 ha, which may produce up to 1 000 metric tonnes in 2003 (FAO correspondent).

Currently, a national strategic plan to produce guidelines on importation and quarantine of aquatic aliens is being formulated by the government based on the FAO CCRF and the FAO/NACA Technical Guidelines

(FAO/NACA, 2000). Once approved by the government, legislation can be drawn up to properly regulate the introduction of *P. vannamei* and other alien species.

Sri Lanka

Sri Lanka is one of the few Asian countries which has yet to import *P. vannamei*. Despite interest in the species due to its perceived tolerance to WSSV, the government has shown great caution due to the potential risks involved with such introductions. They have used existing legislation to prevent introductions, but intend to adopt the FAO and regional guidelines on introduction of alien species to help ensure any importations made are conducted according to established protocols (Sunil Siriwardena, per. com.).

Mainland China and Taiwan Province of China

Mainland China and Taiwan Province of China have not banned the importation of *P. vannamei* or *P. stylirostris*, but have guidelines in place for potential importers. Due to worries over importation of viruses, the Chinese government initiated an aquaculture disease surveillance system. Later, the Chinese Bureau of Fisheries of the Ministry of Agriculture implemented a regulation on aquatic animal epidemic disease prevention, based on the OIE guidelines. Subsequently, in 2001, China entered the WTO and thereby accepted the various relevant protocols and guidelines provided by the WHO, FAO, OIE and so on (Chen Aiping, per. com.).

Mainland China first imported *P. vannamei* in 1988 experimentally from the USA, and then commercially from 1996. They also imported *P. stylirostris* from the USA in 1999/2000. Taiwan Province of China began imports of *P. vannamei* in 1995 from USA (Table 2).

The existing regulations have proven difficult to enforce, and it has been estimated that Mainland China imported more than ten thousand million wild and cultured PL shrimp in 2002. The ineffectiveness or belated enactment of these regulations is also demonstrated by the appearance of viral pathogens including TSV, LOVV, REO III and BP by 1999, probably transferred through the importation of infected stocks of *P. vannamei* and now causing significant disease problems (Chen Aiping, per. com.).

Since there have never been outright bans on importation of alien shrimp, the industries for *P. vannamei* in Mainland China and Taiwan Province of China are longer established and more advanced than those of the other Asian countries, with an estimated 71 percent (300 000 of 420 000 metric tonnes) and 40 percent (8 000 of 19 000 metric tonnes) respectively of their production comprising *P. vannamei* (Table 3).

It seems likely that more countries will impose restrictions and/or more strictly enforce the existing restrictions on the import of non-indigenous shrimp species in an effort to control the currently unknown effects of such importations. This is particularly with regard to the importation of alien viruses that might compromise native shrimp populations, both wild and cultured, as well as other unknown effects on the genetic diversity and ecology of native fauna.

How effective these official bans will be remains to be seen, but past experience has shown that the private sector activities are difficult to control if the perceived rewards are great, as appears to be the case with *P. vannamei*.

7.3 Constraints to effective control of shrimp movements in the Asia-Pacific region

Although the Asia-Pacific region has been working hard to improve safe transboundary movement of live aquatics and despite the various codes and guidelines that have been developed and agreed upon, most of those efforts have been largely ineffective at preventing the spread of alien shrimp and their viral pathogens. This scenario is not specific to the Asia-Pacific region but is also true for the Americas. The possible reasons behind this are varied and include the following:

Producer driven importations

In many cases, even though governments have guidelines and/or regulatory frameworks are in place to restrict movement of shrimp species, the private sector has gone ahead with such imports using illegal or illicit procedures. Thus, although there may be good reasons for limiting imports and to have regulations in place, these have little chance of success in limiting imports unless either the private sector can be convinced of their validity and importance or state law enforcement is improved. It is almost impossible to stop such imports, which are generally taken through illegal channels, unless strong public awareness programmes aimed at improving farmers and producer understanding of the risks involved are implemented.

Perceived benefits of introduced species

The largely private sector introductions are done, whether or not official restrictions are in place, due to the perceived benefits offered by the introduced species. Thus, in the case of *P. vannamei* introductions into Asia, the current perceptions that: *P. vannamei* are more disease resistant than the indigenous species (*P. monodon* and *P. chinensis*), SPF broodstock can be purchased that are free from disease, and that they are more able to tolerate high density, often low-salinity culture, are the main driving forces behind their introduction. Whether these perceived benefits (as detailed in Section 4 and Table 4) are true or not is often irrelevant, particularly when Asian shrimp farmers are struggling to make money using their traditional native species. In this case, as has been seen in virtually all Asian shrimp-producing countries in the past few years, the perception of the private sector is that the potential advantages outweigh the disadvantages and so the importations are made.

Whether this perception is correct or not remains unproven. On the positive side, the Asian *P. vannamei* culture industry has seen a rapid expansion in the last few years, so that production of *P. vannamei* has surpassed that of traditional native cultured species in Mainland China, is rapidly approaching that level in Taiwan Province of China and Thailand, and is gaining increasing importance in Viet Nam and Indonesia (Table 3). The generally downward trend in Asian shrimp production during the 1990s, due largely to disease problems with *P. monodon* and *P. chinensis,* has thus now been reversed with the introduction of the relatively more tolerant *P. vannamei*.

On the negative side, the introduction of *P. vannamei* into Asia has been accompanied by the importation of various viruses, including TSV (already causing losses in Mainland China, Taiwan Province of China and Thailand) and LOVV (possibly responsible for the slowing growth rate of *P. monodon*) and probably others (Section 6.3). The long-term effects of these viruses is unknown, but precedents from introductions of shrimp and their viruses from Asia to Latin America (*i.e.* IHHNV in 1981 and WSSV in 1999) are known to have resulted in severe setbacks to the shrimp culture industry and the socio-economic status of many countries. Additionally, the associated impacts of transboundary introductions of shrimp have unknown, but possibly serious, consequences for wild shrimp populations and genetic diversity (Section 6.2).

The rapid expansion of culture of *P. vannamei* in the Asian region has more recently resulted in marketing problems. Increased production of the same species with a similar size range has led to recent price collapses. Low shrimp prices have led to disputes over alleged ‘shrimp dumping’. This has further reduced confidence amongst producers who, in some cases, are shifting back to *P. monodon* in the hope that these will fetch a higher price.

Limitations on law enforcement

Even where legislation on transboundary movements has been enacted, the extensive borders, lack of resources, lack of clear understanding and knowledge, and weak regulatory structures of many countries make enforcement very difficult, expensive and sometimes impossible. Although such measures for the establishment, enforcement and dissemination of laws and guidelines for the benefit of the aquaculture sector are expensive, the potential losses far outweigh the costs involved, as has been proven many times.

Additionally, many countries have officially regulated the importation of alien species, in harmony with existing international codes of conduct, but have then done little to enforce such limitations. This may be through a lack of desire or commitment, or reluctance (or pressure) not to interfere with the competitiveness of the commercial sector.

Effective enforcement requires cooperation between the state and private sector and this can only be achieved through improved dialogue, increased awareness and effective communication with concerned parties regarding the risks involved in introductions and movements. Only a few countries practice effective, science based risk assessment and analysis procedures for the movement of alien or other aquatic species in the Asia-Pacific region and the wider application of proper risk assessment procedures should be encouraged.

Inadequate testing facilities and protocols for viral pathogens

With *P. vannamei* and *P. stylirostris* (unlike *P. monodon*), SPF broodstock and PL are already commercially available (although limited). Despite the fact that this should be an advantage, where regulations have been made (based on published codes of conduct) to permit the importation of disease-free specimens, many problems may still arise.

Such difficulties stem partly from the fact that shrimp are characterized by persistent viral infections that often produce no gross signs of disease or mortality. Thus sophisticated procedures such as Polymerase Chain Reaction (PCR) methodologies may be required to detect these pathogens. Such techniques are fraught with error stemming from poor sampling techniques, sample size and preservation, analysis protocols, interpretation and lack of standardization and/or inter-calibration.

In addition, some viruses remain undetectable until after the shrimp are stressed, for example following spawning of broodstock. This means that stocks must be held in quarantine facilities until such time as they can be spawned, so that the virus can be detected. Such facilities are currently largely unavailable in Asia. Thus, even where facilities exist, competent and accurate analysis of the disease status of the imported shrimp is still not always possible.

Lack of understanding of viral pathogen transfer pathways

The pathways of viral pathogen transfers in shrimp are still far from clear. With uncertainties regarding which sources carry high risk of viral transfer, it is difficult to design protocols for testing imported products. It seems clear that the importation of live animals offers the most high-risk route of infection, so that these should be the main focus of attention. However, the level of risk involved with other possible sources including green (fresh/frozen) shrimp for bait, processing or direct consumption, ballast water and hull fouling of ships, and aerial transfer through birds and/or insects is less clear. Meanwhile, fresh feeds used in shrimp culture such as Artemia and polychaete worms, cooked shrimp and shrimp head meal appear to carry little or no risk and may not need to be tested (Flegel, 2003).

Incomplete inventory of potential pathogens

Even where imported shrimp are subjected to thorough analysis for pathogens, there is a limit on the number of pathogens that are monitored. It is believed that there may exist many “hidden” or “cryptic” viruses within shrimp that are unknown and therefore impossible to detect. Certainly, the number of known viruses currently affecting cultured shrimp is growing every year.

In addition, viruses that may not infect or cause disease and mortality in one species, may have other effects in other species. Therefore, when planning which viruses much be checked, consideration must be made not just of the viruses that can infect the shrimp being imported, but also of those capable of infecting native species. Unfortunately, current understanding of the effects of many viruses on different shrimp hosts is limited, making such disease testing even more difficult.

A discussion of the recommendations proposed for controlling transboundary movements of shrimp and limiting viral spread are presented in the following Section.

Mistaken perceptions of SPF and SPR shrimp

A common perception amongst farms is that SPF and SPR shrimp are ‘disease-free’. Although the original stock of SPF or SPR shrimp may be certified as clear of specific pathogens or resistant certain strains, the animals produced from this stock may not be so reliable, particularly if the biosecurity of the producing facility is poor. The sale of shrimp (either for use as broodstock or for stocking) that are claimed to be SPF or SPR because they were bred from SPF stocks is an example of how farmers may be misled regarding the quality of the animals they are buying and how disease can actually be spread by unsuspecting farmers.

The effective control and regulation of facilities that produce SPF/SPR shrimp and adequate diagnostic support for health testing are two areas where national effort can be concentrated to ensure that farmers get what they expect and that disease problems are solved rather than created by the use of SPF/SPR stocks.

8. Summary and recommendations

Increasing concern over the effects of previous transboundary movements of pathogens has led to the establishment of codes and guidelines for health management and movement of live aquatic organisms. Such codes and guidelines, developed by various global and regional organizations (ICES, OIE, FAO, etc.), have been in place for some time, whilst new agreements specific to Asia-Pacific, although voluntary, have been also established recently by FAO, NACA, SEAFDEC and ASEAN (as described in Section 7.1). Despite their official adoption and the establishment of national legislation and regulatory frameworks (to varying degrees) by several Asian countries involved, they have so far failed to prevent repeated transboundary movement of *P. vannamei* and *P. stylirostris* and in many cases their attendant serious viral pathogens.

The restrictions placed by various governments of the Asia and the Pacific are discussed in Section 7.2. Very few Asian countries have so far managed to completely prevent the introduction of *P. vannamei* (*i.e.* Sri Lanka). Most have allowed importation of some, supposedly disease free PL or broodstock, under government supervision (in many cases without adequate facilities to verify quality and without conducting proper risk assessments). However, in nearly every case, the difficulty or expense involved with such introductions, combined with the impatience of shrimp farmers (who have seen declining revenues due to the effects of previously introduced viral pathogens) have circumvented the official process and illegally brought in cheaper animals which are not certified disease free. Such a scenario has been seen in Thailand, Indonesia, the Philippines, India, Viet Nam and Malaysia, all within the last two to five years. In the cases of Thailand and Indonesia, and probably the other countries (although this remains to be confirmed), such movements have already led to the introduction of at least one notifiable and serious pathogen of cultured and wild shrimp, the Taura Syndrome Virus (TSV). There are also suspicions that other viral pathogens have been introduced along with the *P. vannamei*, which may have led to problems with the primary indigenous cultured shrimp species *P. monodon* (*i.e.* LOVV in Thailand).

There exist many reasons for the ineffectiveness of these restrictions, which have allowed the illegal importation of PL and broodstock animals that have not originated from disease free facilities (as stipulated in the codes), in most cases by the private sector. Most problems have involved the predominance of producers in driving such imports due to the perceived benefits of the introduced species. The possible reasons are detailed in Section 7.3.

Nonetheless, in the short term at least, significant industries based upon the introduction and culture of *P. vannamei* into these countries, and *P. stylirostris* into Brunei, have developed. The culture of these alien species is beginning to replace the culture of indigenous species which have suffered chronic disease problems, leading to declining production throughout Asia during the past decade. Ironically, it appears possible that at least some of the problems encountered with the indigenous species may have resulted from viruses imported with their alien shrimp hosts.

The only Asian countries not to have placed limitations on the importation of *P. vannamei* from any source were Mainland China and Taiwan Province of China, who have imported this species in great quantities (initially) over the past eight years. This resulted in the simultaneous introduction of TSV and other viral pathogens. Although TSV is currently causing serious mortalities in cultured *P. vannamei* in these countries, it has not yet been proven to result in problems for other shrimp species. Neither has it prevented the massive expansion of *P. vannamei* farming in these countries, such that it has now reached 300 000 metric tonnes (71 percent of estimated total shrimp production in 2003) in Mainland China and 8 000 metric tonnes (42 percent of estimated total shrimp production in 2002) in Taiwan Province of China. However, the successful development of the culture industry for *P. vannamei* in China has led to the export of non disease-free stocks, which appear to have contaminated other Asian countries with pathogenic viruses.

Since it is clear that the majority of Asian countries have already introduced *P. vannamei* (either legally or illegally) to some extent, there is now some determination to try and ensure that any negative impacts are minimized. Some countries are considering enforcing their official bans and destroying all stocks found within their borders (*i.e*. the Philippines and Malaysia). Short of this difficult (and perhaps legally unenforceable) procedure, the species, and in most cases, its associated viruses, will remain in most countries.

A more pragmatic approach might be the investigation and elimination of all stocks infected with known pathogens, followed by an opening of the borders only to certified disease-free stocks. This assumes that the testing of stocks for import and the necessary controls for this could be strengthened, since it has been the inability to effectively control imports which has allowed the introductions to date.

This approach at least offers a working solution to the reality that *P. vannamei* is already present in many countries and being cultured at significant economic levels in several. This also allows countries to take advantage of the potential benefits offered with this alien species and would encourage a more responsible approach to the issue of shrimp movements and disease in the region. What is certain is that blanket bans on the importation of species (such as *P. vannamei*) which are desired by the commercial sector are ineffective at preventing their introduction under current conditions in Asia.

Some North and Latin American countries have shown that even with the introduction of the alien *P. vannamei*, it is possible to limit the introduction of viral pathogens and develop sustainable industries. Examples of this have been seen (despite initial mistakes) in Hawaii and the USA, which have managed to eradicate WSSV from their culture industries, however, the subsequent re-entry or re-emergence of the disease in Hawaii underlines the importance of continued monitoring and surveillance. Similarly, the creditable efforts of Brazil and Venezuela, who have initially prevented the introduction of WSSV and have growing industries for *P. vannamei,* are also threatened by irresponsible movements.

These successes were facilitated by some of the properties of *P. vannamei* (shared by *P. stylirostris*) that provide them with the potential to be introduced to new countries/regions and generate successful industries, without the problems of simultaneously introducing new pathogens. These properties are associated with the fact that the life cycle of these species has been closed and (partially) domesticated strains of genetically selected, fast growing, disease free (SPF) and disease resistant (SPR) animals are commercially available. These properties are not shared by *P. monodon*, the leading cultured shrimp of Asia (although work is in progress), but are common to the vast majority of animals cultured by humans today.

It was through the use of these lines and the strict application of the codes of conduct and health management strategies mentioned above that the American countries were able to successfully introduce these alien species without negative biological consequences. Conversely, it was through the disregard of these principles that the negative aspects of introducing *P. vannamei* to Asia were able to proliferate. Clearly, it is possible to minimize the risks associated with transboundary introductions of these species and the following recommendations are made in that regard.

The broader ecological impacts of the introduction of alien shrimp species such as *P. vannamei* and *P. stylirostris* has been neither well studied nor well documented in the Asia-Pacific. Perceived risks and potential impacts remain unresolved and any country considering the introduction of these alien species should certainly conduct comprehensive risk analysis and assessment, including environmental, social, and economical risks involved with such movements.

8.1 Recommendations for controlling the introduction and culture of *P. vannamei* and *P. stylirostris* in Asia

This review examines the history of introductions of alien Penaeid shrimp species to the Asia-Pacific region and current knowledge of the social, economic and environmental impacts of these introductions.

Present information on impacts is currently very much focused on disease problems, reflecting the major concern of the shrimp industry. An understanding of the impacts on aquatic biodiversity, and indeed the social and economic costs and benefits over anything much beyond the duration of a crop cycle from these alien shrimp introductions, is much more limited. Nevertheless, there are clearly a number of lessons that can be learned from the present situation and recommendations that can made from present experiences. These span advice to both governments and the private sector in countries where these alien species have not been introduced, or where there have been limited introductions to date.

These recommendations also draw on other recent publications regarding the health implications of the importation and sustainable culture of alien shrimp species (and their attendant pathogens), particularly the review made on the management strategies for major diseases in shrimp culture, based on a workshop held in Cebu, Philippines in 1999 (WB/NACA/WWF/FAO, 2001). The focus is on the issues involved with the transboundary introduction and management of *P. vannamei* and *P. stylirostris* in Asia.

Legislation, policy and planning

1. Governments should adopt the import risk analysis (IRA) approach to assess the impacts of introduction of alien shrimp species, and use the IRA process to management measures to reduce identified risks.

2. Nations without established alien shrimp industries should undertake IRA before any further attempts to establish this industry because of the significant potential negative impacts on the existing industry, farmers and aquatic biodiversity.

3. Alien Penaeid shrimp farming is occurring in several countries without a clear planning or management framework. This restricts efforts to manage adverse impacts, such as spread of alien viruses. In such cases, governments are therefore urged to urgently formulate plans for comprehensive management strategies for alien shrimp species, giving consideration to both environmental and disease control issues.

4. Without effective policies and a management framework to address the risks of alien shrimp aquaculture, introductions of alien shrimp are not recommended.

Disease management issues

5. Develop or strengthen contingency plans for addressing diseases of alien species and take action to eradicate, where possible, alien viruses before such problems become established in the industry and wild stocks. Contingency plans should be developed specifically to address alien viruses, notably Taura Syndrome Virus.

6. For countries with established industries, practical measures to reduce risks from importing new diseases should be established. This will require a close working closely with the private sector, addressing the following procedures:

   – importing shrimp only from facilities with demonstrated disease absence. This would require that shrimp exports have a minimum two year disease-free status, are certified as such and can submit independent, qualified certification of their status;
   – restrict severely the import of shrimp coming from uncertified sources of shrimp;
   – submit properly collected samples of imported shrimp to certified disease diagnosis laboratories for assurance of disease-free status, whist maintaining shrimp in biosecure quarantine facilities before release into the environment;
   – conduct cohabitation trials of all imports with indigenous shrimp species to prevent the entry of unknown pathogens that pose high risks to local species;

- develop biosecure high-health maturation systems and hatcheries for alien shrimp species with functional quarantine systems for holding imported animals whilst they are screened, and training facilities/extension for the local farmers; and
- develop a programme for the culture and genetic selection of alien and indigenous species to aid development of improved broodstock with desirable culture characteristics, and training of farmers/extension agents in this technology.

7. Urgently prepare and circulate guidelines on introduction and management of disease in alien shrimp. This should include information on SPF, SPR, and measures required to reduce disease risks, building on the outline frameworks provided in Annexes 1 and 2 of this report.

Environmental and biodiversity concerns

8. Research on ecological and biodiversity impacts of *Penaeus vannamei* and *P. stylirostris* should be conducted urgently, including studies of the extent to which these alien shrimp species are breeding in natural environments, and their actual and potential impacts on wild shrimp stocks.

Codes of conduct, practice, guidelines and management of impacts

9. Codes of conduct and other guidelines in use for shrimp farming in Asia should be reviewed and amended as required more specifically for alien species. Farm management and hatchery management measures should be adopted to reduce risks of escape. This may require zoning of farms away from coastal areas, or other measures to reduce escapes of alien species to the environment.

Markets and price trends

10. Given the present (2004) low market prices for alien shrimps, careful consideration should be given to further expansion of this industry in Asia; further expansion will lead to even greater pressures on prices and competition. In such situations, only larger, integrated companies that can benefits from cost reductions are likely to be able to remain competitive, and benefits to small holders are likely to be limited.

11. Where governments are concerned with the control of the culture of *P. vannamei* and other alien shrimp species, restricting market access for alien shrimp species to constrain farming such as making it illegal to possess or trade in alien shrimp, might be considered.

12. There is a slow trend towards eco-labelling and certification of shrimp in international shrimp markets. The environmental advantages of *P. vannamei (*particularly its requirement for lower protein use) provide some advantages to this species for an environmental certification or labelling scheme.

13. Most international Codes of Conduct, as well as new trace-ability requirements from the US and EU, will require that shrimp are produced from legal farm operations. Therefore, the legal status of *P. vannamei* farming in a country should be carefully considered, and clarified if necessary.

14. Some organic farm certification schemes allow only culture of native species, so the farming of *P. vannamei* in an Asian country might prevent inclusion in such schemes.

Other issues

15. Alien species have proved attractive to farmers because of their domesticated status. There should be further investment in *P. monodon* domestication programs to assist in supporting and encouraging farmers to use indigenous species.

16. Investment should be promoted in research and development of other indigenous shrimp species.

17. Improvements should be made in information dissemination and increased farmer awareness of issues involved with the importation and culture of alien shrimp so that farmers have the facts and can clearly understand the potential risks and benefits involved. Collaboration between farmer's associations and the relevant government agencies would assist this process.

Regional and international cooperation

18. Understanding of the impact and management of alien species is restricted because of a lack of reporting of the species, including reporting of disease outbreaks to OIE and NACA in the region. Contingency plans should be formulated to address diseases.

19. The FAO Code of Conduct for Responsible Fisheries emphasizes the importance of states consulting with neighbours before introductions. This has not happened, and the lack of consultation has hampered assessment and management of impacts. The importance of such consultation is emphasized.

8.2 Recent guidelines, code of practice and other instruments

– A series of guidelines and recommendations for health management in shrimp hatcheries and growout ponds were made at the *Workshop on Management Strategies for Major Diseases in Shrimp Aquaculture* in the Philippines in 1999 (WB/NACA/WWF/FAO, 2001). The principal recommendations of this workshop are presented in Annex I.

– The recent FAO publication *Health Management and Biosecurity Maintenance in White Shrimp (Penaeus vannamei) Hatcheries in Latin America* (FAO, 2003) provides information on how to improve the health and quality of *P. vannamei* postlarve produced in hatcheries in Latin America through improved facility maintenance and husbandry, broodstock maturation, larval rearing, feeding, water quality management, biosecurity, and health management, using interventions at different points of the hatchery production process.

– The document also provides valuable information on how Hazard Analysis Critical Control Points (HACCP) type interventions could be applied during hatchery production of *P. vannamei* postlarvae. The information provided in this document will contribute to the efforts by the *P. vannamei* hatchery operators and mangers in producing quality, disease-free, healthy post larvae, thus improving overall production and sustainability of white shrimp aquaculture.

– The major protocols detailed in the FAO (2003) document are given in Annexes II and III.

9. References

Adams, T., Bell, J. & Labrosse, P. 2001. Current status of aquaculture in the Pacific islands. *In:* R.P. Subasinghe, P. Bueno, M.J. Phillips, C. Hough, S.E. McGladdery & J.R. Arthur, eds. Aquaculture in the Third Millennium. Technical Proceedings of the Conference on Aquaculture in the Third Millennium, Bangkok, Thailand, 20-25 February 2000. pp. 295-305. NACA, Bangkok and FAO, Rome.

Alciver-Warren, A., Garcia, D. K., Dhar, A.K., Wolfus, G.M. & Astrofsky, K.M. 91997. Efforts toward mapping the shrimp genome: A new approach to animal health. *In*: T.W. Flegel & I.H. MacRae eds. Diseases in Asian Aquaculture III. Fish Health Section, pp. 255-263. Manila, Asian Fisheries Society.

Alday de Graindorge, V. 2002. Standardization of PCR techniques. *Global Aquaculture Advocate*, December 2002. pp. 55-56.

Alday de Graindorge, V. & Griffith, D. 2000. Ecuador. *In*: Thematic review on Management Strategies for Major Diseases in Shrimp Aquaculture. A component of the WB/NACA/WWF/FAO Program on Shrimp Farming and the Environment. Report of the workshop held in Cebu, Philippines from 28-30 November 1999. pp. 17-19.

APHIS (Animal and Plant Health Inspection Service) website: http://www.aphis.usda.gov

Argue, B.J., Arce, S.M., Lotz, J.M. & Moss, S.M. 2002. Selective breeding of Pacific white shrimp (*Litopenaeus vannamei*) for growth and resistance to Taura Syndrome Virus. *Aquaculture* 204(3-4): 447-460.

Benzie, J.A.H. 2000. Population genetic structure in Penaeid prawns. *Aquaculture Research* 31(1): 95-119.

Bierne, N., Beuzart, I., Vonau, V., Bonhomme, F. & Bedier, E. 2000. Inbreeding depression in a Penaeid shrimp. *Aquaculture* 184: 203-219.

Brock, J.A. 1997. Special topic review: Taura syndrome, a disease important to shrimp farms in the Americas. *World Journal of Microbiology and Biotechnology*. 13: 415-418.

Brock, J.A. 1992. A brief overview of some historical and current issues concerning Penaeid shrimp introductions into Hawaii. *In:* M.R. DeVoe, ed. Introductions and transfers of marine species. pp. 187-189. South Carolina Sea Grant Consortium.

Brock, J.A. & Main, K.L. 1994. A guide to the common problems and diseases of cultured *Penaeus vannamei*. World Aquaculture Society, Baton Rouge, Louisiana, USA, 242 pp.

Brock, J.A. Gose, R.B., Lightner, D.V. & Hasson, K. 1995. An overview on Taura syndrome, an important disease of farmed *Penaeus vannamei*. *In*: C.L. Browdy & J.S. Hopkins, eds. Swimming through troubled water. Proceedings of the special session on shrimp farming, pp. 84-94. Aquaculture ’95, WAS, USA.

Brock, J.A., Gose, R.B., Lightner, D.V. & Hasson, K. 1997. Recent developments and an overview of Taura Syndrome of farmed shrimp in the Americas. *In*: T.W. Flegel & I.H. MacRae, eds. Diseases in Asian Aquaculture III. Fish Health Section, Asian Fisheries Society, Manila, pp. 275-283.

Brown, P. Jr. 2002. Shrimp markets shifting in Asia? *Global Aquaculture Advocate*, December 2002, p. 17.

Carr, W.H., Fjalestad, K.T., Godin, D., Swingle, J., Sweeney, J.N. & Gjedrem, T. 1997. Genetic variation in weight and survival in a population of specific pathogen-free shrimp, *Penaeus vannamei*. *In*: T.W. Flegel & I.H. MacRae, eds. Diseases in Asian Aquaculture III, Fish Health Section, pp. 265-271. Manila, Asian Fisheries Society.

Chamberlain, G. 2003. World shrimp farming: progress and trends. World Aquaculture 2003, Salvador, Brazil, May 20, 2003.

Chanratchakool, P. 2003. Minimizing risks from introduction of new shrimp species. Presentation at the Aquamarkets Shrimp Session, Manila, Philippines, June 2-6, 2003.

Chanratchakool, P., Fegan, D.F. & Phillips, M.J. 2000. Thailand. *In*: Thematic review on Management Strategies for Major Diseases in Shrimp Aquaculture. A component of the WB/NACA/WWF/FAO Program on Shrimp Farming and the Environment. Report of the workshop held in Cebu, Philippines, 28-30 November 1999. pp. 85-90.

Cámara Nacional de Acuacultura (CNA) website: http://www.cna-ecuador.com

Center for Tropical and Subtropical Aquaculture (CTSA). 1996. Shrimp diseases, publication No. 121, May 1996, 2 pp.

Corrales, H.L., Watson, C.L. & Wigglesworth, J. 2000. Honduras. *In:* Thematic review on Management Strategies for Major Diseases in Shrimp Aquaculture. A component of the WB/NACA/WWF/FAO Program on Shrimp Farming and the Environment. Report of the workshop held in Cebu, Philippines, 28-30 November 1999. pp. 20-23.

De Barros Guerrelhas, A.C. 2003. Shrimp hatchery development in Brazil. *Global Aquaculture Advocate*, April 2003, pp. 67-70.

De Paiva Rocha, I. 2003. Shrimp aquaculture grows in Brazil. *Global Aquaculture Advocate*, April 2003, pp. 71-73.

East, I.J., Black, P.F., Findlay, V. & Bernoth, E-M. 2002. A national survey to demonstrate freedom from white spot virus and yellow head virus in Australian crustaceans. ISAAH, 2002.

Eldridge. L.G. 1995. Introduction of commercially significant aquatic organisms to the Pacific Islands. Penaeid Shrimps pp. 91-95. SPC Inshore Fisheries Research Project Technical Document No. 7. SPREP Reports and Studies Series No. 78. ISSN 1018-3116, Website: http://www.spc.int

FAO. 1995. FAO code of conduct for responsible fisheries. Rome, FAO. 1995. 41 pp.

FAO. 1997. FAO technical guidelines for responsible fisheries. No. 5. Rome, FAO. 1997. 40 pp.

FAO. 2003. Health Management and Biosecurity Maintenance in White Shrimp (*Penaeus vannamei*) Hatcheries in Latin America. *FAO Fisheries Technical Paper*. No. 420. Rome, FAO. 58 pp.

FAO FISHSTAT Plus website: http://www.fao.org/fi/statist/fisoft/FISHPLUS.asp

FAO/NACA. 2000. Asia Regional Technical Guidelines on Health Management for the Responsible Movement of Live Aquatic Animals and the Beijing Consensus and Implementation Strategy. NACA, Bangkok and FAO, Rome.

FAO/NACA/OIE. 1998. First training workshop of the FAO/NACA/OIE Regional Program for the development of Technical Guidelines on Quarantine and Health Certification and Establishment of Information Systems, for the Responsible Movement of Live Aquatic Animals in Asia. Bangkok, Thailand, 16-20 January 1998. FAO TCP/RAS/5714 Field Doc. No. 1, Bangkok, 142 pp.

Fegan, D. 2000. International trade in live shrimp: Part I. *Global Aquaculture Advocate*, December 2000, pp. 22-23.

Fegan, D. 2002. Is vannamei fever sustainable in Asia? *Global Aquaculture Advocate*, December 2002, pp. 15-16.

Fegan, D., Arthur, J.R., Subasinghe, R.P., Reantaso, M.B., Alday de Graindorge, V. & Phillips, M.J. 2001. Consultant report: A review of transboundary aquatic animal pathogen introductions and transfers. In: Report of the Puerto Vallata Expert Consultation. APEC/FAO/NACA/SEMERNAP, 2001. pp. 132-175.

Flegel, T.W. 2003. Problematic transfer of viruses amongst Penaeid shrimp. Presentation at the Aquamarkets Shrimp Session, Manila, Philippines, June 2-6, 2003.

Flegel, T.W. & Fegan, D. 2002a. Preventing the spread part one. *Asian Aquaculture Magazine,* May/June 2002. pp. 17-19.

Flegel, T.W. & Fegan, D. 2002b. Preventing the spread part two. *Asian Aquaculture Magazine*, July/August 2002. pp. 18-20 (& 40).

Flegel, T.W., Boonyaratpalin, S. & Withyachumnarnkul, B. 1997. Progress in research on yellow-head virus and white-spot virus in Thailand. *In*: T.W. Flegel and I.H. MacRae, eds. Diseases in Asian Aquaculture III. Fish Health Section, pp. 285-295. Manila, Asian Fisheries Society.

Flegel, T.W., Chanratchakool, P., Mohan, C.V. & Lavilla-Torres, C.R. 2003. Transboundary movement of alien shrimp species in the Asian region. Compiled information on presentations at the Aquamarkets Shrimp Session, Manila, Philippines, June 2-6, 2003.

Garza, J.R., Hasson, K.W., Poulos, B.T., Redman, R.M., White, B.L. & Lightner, D.V. 1997. Demonstration of infectious Taura Syndrome Virus in the feces of seagulls collected during an epizootic in Texas. *Journal of Aquatic Animal Health* 9: 156-159.

Global Aquaculture Alliance (GAA) website: http://www.gaalliance.org

Globefish Website: Monthly market reports on shrimp. http://www.globefish.org/marketreports/Shrimp/Shrimp

Goyard, E., Patrois, J., Peignon, M., Vanaa, V., Dufor, R., Viallon, V. & Bedier, E. (2002). Selection for better growth of *Penaeus stylirostris* in Tahiti and New Caledonia. *Aquaculture* 204(3-4): 461-468.

Gulf States Marine Fisheries Commission (GSMFC) website. Species summaries: http://www.gsmfc.org/nis.

Hasson, K.W., Lightner, D.V., Poulos, B.T., Redman, R.M., White, B.L., Brock, J.A.E. & Bonami, J.R. 1995. Taura syndrome in *Penaeus vannamei*: demonstration of a viral etiology. *Diseases of Aquatic Organisms* 23: 115-126.

Hennig, O.L. & Arce, S.M. 2003. SPF fleshy prawns show potential for genetic improvement. *Global Aquaculture Advocate*, April 2003, p. 30.

Hernández-Rodríguez, A., Alceste-Oliviero, C., Sánchez, R., Jory, D., Vidal, L. & Constain-Franco, L.-F. 2001. Aquaculture development trends in Latin America and the Caribbean. *In:* R.P. Subasinghe, P. Bueno, M.J. Phillips, C. Hough, S.E. McGladdery & J.R. Arthur, eds. Aquaculture in the Third Millennium. Technical Proceedings of the Conference on Aquaculture in the Third Millennium, Bangkok, Thailand, 20-25 February 2000. pp. 317-340. NACA, Bangkok and FAO, Rome.

Hizer, S.E., Dhar, A.K., Klimpel, K.R. & Garcia, D.K. 2002. RAPD markers as predictors of infectious hypodermal and haematopoietic necrosis virus (IHHNV) resistance in shrimp (*Litopenaeus stylirostris*). *Genome* 45(1): 1-7.

Hossain, Md.S., Chakraborty, A., Joseph, B., Otta, S.K., Karunasagar, I. & Karunasagar, I. 2001. Detection of new hosts for white spot syndrome virus using nested polymerase chain reaction. *Aquaculture* 198 (1-2): 1-11.

ICES. 1995. ICES code of practice on the introduction and transfers of marine organisms 1994. Annex 3 of the *Report of the Advisory Committee on the Marine Environment*, 1994. ICES Cooperative Research Report No. 204.

Instituto Nacional de Pesca (INP) Ecuador website; http://www.inp.gov.ec

Jiang, Y. 2000. Mainland China. *In*: Thematic review on Management Strategies for Major Diseases in Shrimp Aquaculture. A component of the WB/NACA/WWF/FAO Program on Shrimp Farming and the Environment. Report of the workshop held in Cebu, Philippines from 28-30 November 1999. pp. 74-78.

Jie, K., Qingwen, Z., Ping, L. & Jianhai, X. 2003. Selective breeding raises WSSV resistance in fleshy prawns. *Global Aquaculture Advocate*, April 2003, pp. 25-26.

Jiménez, R, Barniol, R. & Machuca, M. 1997. An epizootic of an intracellular bacterium in cultured Penaeid shrimp (Crustacea, Decapoda) in the Gulf of Guayaquil, Ecuador. *In*: T.W. Flegel & I.H. MacRae, eds., Diseases in Asian Aquaculture III. Fish Health Section, pp. 305-311. Manila, Asian Fisheries Society.

Jiménez, R., Barniol, R., de Barniol, L. & Machuca, M. 1999. Infection of IHHN virus in two species of cultured Penaeid shrimp *Litopenaeus vannamei* (Boone) and *Litopenaeus stylirostris* (Stimpson) in Ecuador during El Niño 1997-98. *Aquaculture Research* 30(9): 695.

Joint Sub-committee on Aquaculture (JSA). 1997. An evaluation of potential virus impacts on cultured shrimp and wild shrimp populations in the Gulf of Mexico and Southeastern US Atlantic coastal waters. National Marine Fisheries Service, National Program Office, 1315 East-West Highway, Silver Spring, MD 20910. 65 pp.

Jones, K. & Lai, L. 2003. Diversity loss in captive-breeding programmes for shrimp. *Global Aquaculture Advocate* 6(1): 31-32.

Khoa, L.V., Hao, N.V. & Huong, L.T.L. 2000. Viet Nam. *In*: Thematic review on Management Strategies for Major Diseases in Shrimp Aquaculture. A component of the WB/NACA/WWF/FAO Program on Shrimp Farming and the Environment. Report of the workshop held in Cebu, Philippines, 28-30 November 1999. pp. 91-94.

Kongkeo, H. 2001. Current status and development trends of aquaculture in the Asian region. *In:* R.P. Subasinghe, P. Bueno, M.J. Phillips, C. Hough, S.E. McGladdery and J.R. Arthur, eds. Aquaculture in the Third Millennium. Technical Proceedings of the Conference on Aquaculture in the Third Millennium, Bangkok, Thailand, 20-25 February 2000. pp. 267-293. NACA, Bangkok and FAO, Rome.

Larramore, S.E., Montiel de Moprales, M., Laramore, C.R. & Scarpa, J. 2002. Putative attenuated infectious hypodermal and haematopoietic necrosis (IHHN) virus: case study with *Litopenaeus vannamei*. ISAAH, 2002.

Lightner, D.V. 1993. Diseases of cultured Penaeid shrimp. Pp. 393-486. *In*: James P. McVey, ed. CRC Handbook of Mariculture, 2nd Edition, Volume I, Crustacean Aquaculture. Boca Raton, Florida, CRC Press.

Lightner, D.V. 1995. Taura syndrome: an economically important viral disease impacting the shrimp farming industries of the Americas including the United States. *In:* Proceedings of the ninety-ninth annual meeting USAHA, Reno, Nevada. pp. 36-52.

Lightner, D.V. 1996a. Epizootiology, distribution and the impact on international trade of two Penaeid shrimp viruses in the Americas. Revue Scientifique et Technique, *OIE* 15(2): 579-602.

Lightner, D.V. 1996b. A handbook of shrimp pathology and diagnostic procedures for diseases of cultured Penaeid shrimp. Baton Rouge, Louisiana, USA. The World Aquaculture Society.

Lightner, D.V. 1999. The Penaeid shrimp viruses TSV, IHHNV, WSSV and YHV: Current status in the Americas, available diagnostic methods and management strategies. *Journal of Applied Aquaculture* 9(2): 27-52.

Lightner, D.V. 2002. Introduction of non-indigenous shrimp viruses and their potential impact on farmed and native wild shrimp populations. ISAAH, 2002.

Lightner, D.V. & Redman, R.M. 1998a. Strategies for the control of viral diseases of shrimp in the Americas. *Fish Pathology* 33: 165-180.

Lightner, D.V. & Redman, R.M. 1998b. Emerging crustacean diseases. *In*: Third International Symposium on Aquatic Animal Health, Aug 30-Sept 3, 1998, Baltimore, Maryland, USA. 6 pp.

Lightner, D.V., Redman, R.M., Hasson, K.W. & Pantoja, C.R. 1995. Taura syndrome in Panaeus vannamei (Crustacea, Decapoda): gross signs, histopathology and ultrastructure. *Diseases of Aquatic Organisms* 21: 53-59.

Lightner, D.V. *et al.* 2002. Six morphologically-distinguishable populations of *P. stylirostris*. *Marine Biology* 137(5-6): 875.

Lotz, J.M. 1997. Disease control and pathogen status assurance in an SPF-based shrimp aquaculture industry, with particular reference to the United States. *In*: T.W. Flegel & I.H. MacRae eds., Diseases in Asian Aquaculture III. Fish Health Section, pp. 243-254. Manila, Asian Fisheries Society.

Lu, Y., Tapay, L.M., Bock, J.A. & Loh, P.C. 1994. Infection of the yellow head baculo-like virus (YBV) in two species of Penaeid shrimp, *Penaeus stylirostris* (Stimpson) and *Penaeus vannamei* (Boone). *Journal of Fish Diseases* 17: 649-656.

Lu, Y., Tapay, L.M., Loh, P.C., Bock, J.A. & Gose, R.B. 1995. Distribution of yellow head virus in selected tissues and organs of Penaeid shrimp *Penaeus vannamei*. *Diseases of Aquatic Organisms* 23: 67-70.

McCann, J.A., Arkin, L.N. & Williams, J.D. 1996. Non-indigenous aquatic and selected terrestrial species of Florida. University of Florida, Center for Aquatic Plants, http://aquatl.ifas.ufl.edu/mctitle.html

McIntosh, R.P., Drennan, D.P. & Bowen, B.M. 1999. Belize aquaculture: Development of an intensive sustainable, environmentally friendly shrimp farm in Belize. *In*: Green, B.W., Clifford, H.C., McNamara, M. & Montaño, eds. V. Central American Symposium on Aquaculture, Latin American Chapter of the World Aquaculture Society, San Pedro Sula, Honduras, pp. 85-99.

Mohan, C.V. & Basavarajappa, H.N. 2000. India. *In*: Thematic review on Management Strategies for Major Diseases in Shrimp Aquaculture. A component of the WB/NACA/WWF/FAO Program on Shrimp Farming and the Environment. Report of the workshop held in Cebu, Philippines from 28-30 November 1999. pp. 51-58.

Mohan, C.V. 2003. Species introductions: Impacts on aquatic animal health and trade. Presentation at the Aquamarkets Shrimp Session, Manila, Philippines, June 2-6, 2003.

Morales, R., Bercerra, L. & Lara, C. 2000. Panama. *In*: Thematic review on Management Strategies for Major Diseases in Shrimp Aquaculture. A component of the WB/NACA/WWF/FAO Program on Shrimp Farming and the Environment. Report of the workshop held in Cebu, Philippines from 28-30 November 1999. pp. 29-31.

Motte, E., Yugcha, E., Luzardo, J., Castro, F., Leclercq, G., Rodriguez, J., Miranda, P., Borja, O., Serrano, J., Terreros, M., Montalvo, K., Narvaez, A., Tenorio, N., Cedeno, V., Mialhe, E. & Boulo, V. 2003. Prevention of IHHNV vertical transmission in the white shrimp *Litopenaeus vannamei*. *Aquaculture* 219(1-4): 57-70.

NACA/FAO. 2001. Aquaculture in the Third Millennium. *In*: Subasinghe, R.P., Bueno, P.B., Phillips, M.J., Hough, C., McGladdery, S.E. & Arthur, J.R. eds. Technical Proceedings of the Conference on Aquaculture in the Third Millennium, Bangkok, Thailand, 20-25 February 2000. 471 pp. NACA, Bangkok and FAO, Rome.

National Marine Fisheries Service (NMFS) Website. NMFS trade query. http://www.st.nmfs.gov/pls/webpls/trade

Office International des Epizooties (OIE) website: http://www.oie.int

OIE. 2003a. Aquatic Animal Health Code. 2003. (Sixth Edition), 165 pp. OIE, Paris. (also available at http://www.oie.int/eng/normes/fcode/A_summry.htm)

OIE. 2003b. Manual of Diagnostic Tests for Aquatic Animals. 2003. (Fourth Edition), 358 pp. OIE, Paris. (also available at http://www.oie.int/eng/normes/fmanual/A_summry.htm).

Olin, P.G. 2001. Current status of aquaculture in North America. *In*: R.P. Subasinghe, P. Bueno, M.J. Phillips, C. Hough, S.E. McGladdery & J.R. Arthur, eds. Aquaculture in the Third Millennium. Technical Proceedings of the Conference on Aquaculture in the Third Millennium, Bangkok, Thailand, 20-25 February 2000. pp. 377-396. NACA, Bangkok and FAO, Rome.

Overstreet, R.M., Lightner, D.V., Hasson, K., McIlwain, S. & Lotz, J.M. 1997. Susceptibility to Taura Syndrome Virus of some Penaeid shrimp species native to the Gulf of Mexico and the Southeastern United States. Journal of *Invertebrate Pathology* 69: 165-176.

Overstreet, R.M. & Matthews, T. 2002. Effects of temperature on WSSV and TSV in *Litopenaeus vannamei* in controlled experiments. ISAAH, 2002.

Pasharawipas, T., Flegel, T.W., Suriratana, S. & Morrison, D.J. 1997. Latent yellow-head infections in *Penaeus monodon* and implications regarding disease resistance or tolerance. *In*: T.W. Flegel, P. Menasveta & S. Paisarnrat (eds.), Shrimp biotechnology in Thailand. National Center for Genetic Engineering and Biotechnology, Bangkok, pp. 45-53.

Pérez-Velázquez, M., Bray, W.A., Lawrence, A.L., Gatlin III, D.M. & González-Félix, M.L. 2001. Effect of temperature on sperm quality of captive *Litopenaeus vannamei* broodstock. Aquaculture, 198: 3-4. 209-218.

Peterson, J. 2002. Shrimp farming in southeast Mainland China. *In*: B. Rosenberry, ed. World Shrimp Farming 2002, pp. 42-49. *Shrimp News International*.

Robalino, J., Gross, P.S., Warr, G.W., Chapman, R.W. & Browdy, C.L. 2003. Functional genomics studies explore shrimp responses to viral pathogens. *Global Aquaculture Advocate*, April 2003, pp. 28-29.

Roberto Andreatta, E., Beltrame, E. & Winckler da Costa, S. 2002. Pacific white shrimp culture in southern Brazil. *Global Aquaculture Advocate*, December 2002, pp. 76-77.

Rosenberry, B. 2000. World shrimp farming 2000. *Shrimp News International*, 324 pp.

Rosenberry, B. 2001. World shrimp farming 2001. *Shrimp News International*, 316 pp.

Rosenberry, B. 2002. World shrimp farming 2002. *Shrimp News International*, 276 pp.

Rukyani, A. 2000. Indonesia. *In:* Thematic review on Management Strategies for Major Diseases in Shrimp Aquaculture. A component of the WB/NACA/WWF/FAO Program on Shrimp Farming and the Environment. Report of the workshop held in Cebu, Philippines from 28-30 November 1999. pp. 59-64.

Sandifer, P.A., Hopkins, J.S. & Stokes, A.D. 1985. Intensification of shrimp culture in earthen ponds in South Carolina: progress and prospects. *Journal of the World Aquaculture Society* 19(4): 218-226.

SEAFDEC. 2001. Regional guidelines for responsible fisheries in Southeast Asia. Responsible aquaculture. SEAFDEC, Iloilo, Philippines, 2001. 43 pp.

Seafood business website: http://www.seafoodbusiness.com

SEMERNAP. 2000. Mexico. *In*: Thematic review on Management Strategies for Major Diseases in Shrimp Aquaculture. A component of the WB/NACA/WWF/FAO Program on Shrimp Farming and the Environment. Report of the workshop held in Cebu, Philippines, 28-30 November 1999.

Soto, M.A. & Lotz, J.M. 2001. Epidemiological parameters of white spot syndrome virus infections in *Litopenaeus vannamei* and L. Setiferus. *Journal of Invertebrate Pathology* 78: 9-15.

Southwest Regional Office (SWR) of the NMFS website: Japanese frozen shrimp imports, December 2002, http://swr.ucsd.edu/fmd/sunee/shrimp/jshdec02.htm

Subasinghe, R.P.; McGladdery, S.E. & Hill, B.J. 2004. Surveillance and zoning for aquatic animal diseases. *FAO Fisheries Technical Paper*. No. 451. Rome, FAO. 2004. 73 pp.

Talavera, V. & Vargas, L.Z. 2000. Peru. *In*: Thematic review on Management Strategies for Major Diseases in Shrimp Aquaculture. A component of the WB/NACA/WWF/FAO Program on Shrimp Farming and the Environment. Report of the workshop held in Cebu, Philippines from 28-30 November 1999. pp. 32-37.

Tang, K.F. & Lightner, D.V. 2002. Detection and quantification of infectious hypodermal and haematopoietic necrosis virus in Penaeid shrimp by real-time PCR. *Diseases of Aquatic Organisms* 44: 79-85.

Tang, K.F.J., Durand, S.V., White, B.L., Redman, R.M., Pantoja, C.R. & Lightner, D.V. 2000. Postlarvae and juveniles of a selected line of *Penaeus stylirostris* are resistant to infectious hypodermal and hematopoietic necrosis virus infection. *Aquaculture* 190(3-4): 203-210.

Tang, K.F.J., Durand, S.V., White, B.L., Redman, R.M., Mohoney, L.L. & Lightner, D.V. 2002a. Induced resistance to white spot syndrome virus infection in *Penaeus stylirostris* through pre-infection with infectious hypodermal and haematopoietic necrosis virus – a preliminary study. Aquaculture 216(1-4): 19-29.

Tang, K.F.J, Poulos, B.T., Wang, J., Redman, R.M. & Lightner, D.V. 2002b. Geographic variations among infectious hypodermal and haematopoietic necrosis virus (IHHNV) isolates and characteristics of their infection. ISAAH, 2002.

Tapay, L.M., Lu, Y., Gose, R.B., Brock, J.A. & Loh, P.C. 1997. Infection of white-spot baulovirus-like virus (WSBV) in two species of Penaeid shrimp *Penaeus stylirostris* (Stimpson) and *P. vannamei* (Boone). *In:* T.W. Flegel & I.H. MacRae, eds. Diseases in Asian Aquaculture III. Fish Health Section, pp. 297-302. Manila Asian Fisheries Society.

Taw, N., Srisombat, S. & Chandaeng, S. (2002). L. vannamei trials in Indonesia. *Global Aquaculture Advocate*, December 2002, pp. 20-22.

TFRC (Thai Farmers Research Center Co.) website: http://www.tfrc.co.th

The Wave website: http://thewaveonline.com

Thompson, J.A., Davidson, T.J., Frelier, P.F. & Lawrence, A.L. 1997. Epidemiology: what causes shrimp mortality? *In*: T.W. Flegel & I.H. MacRae, eds. Diseases in Asian Aquaculture III. Fish Health Section, pp. 195-201. Manila, Asian Fisheries Society.

Tu, C., Huang, H.T., Chuang, S.H., Hsu, J.P., Kuo, S.T., Li, N.J., Hsu, T.L., Li, M.C. & Lin, S.Y. 1999. Taura syndrome in Pacific white shrimp *Penaeus vannamei* cultured in Taiwan. *Diseases of Aquatic Organisms* 38: 159-161.

UNEP. 1995. Global Biodiversity Assessment. Annex 6, Glossary. UNEP ISBN 0 521 56481 6.

University of Florida/IFAS (UF/IFAS). 2003. Indian River Research and Education Center Aquaculture Advisory Subcommittee Newsletter 1(1): 4 pp.

US Congress, Office of Technology Assessment, 1995. Chapter 2 Aquatic animal Health. *In: Selected Technology Issues in US Aquaculture* (OTA-BP-ENV-171). Office of Technology Assessment, Washington, D.C. pp. 5-17.

US Environmental Protection Agency website: http://www.epa.gov/

Walker, P.J. 2000. Australia. *In*: Thematic review on Management Strategies for Major Diseases in Shrimp Aquaculture. A component of the WB/NACA/WWF/FAO Program on Shrimp Farming and the Environment. Report of the workshop held in Cebu, Philippines from 28-30 November 1999. pp.39-44.

WB/NACA/WWF/FAO. 2001. *In*: Edited by R. Subasinghe, R. Arthur, M.J. Phillips & M. Reantaso, eds. Thematic Review on Management Strategies for Major Diseases in Shrimp Aquaculture. Proceedings of a workshop held in Cebu, Philippines on 28-30 November 1999. 135 pp.

Wyban, J. 2002. White shrimp boom continues. *Global Aquaculture Advocate*, December 2002, pp. 18-19.

Wyban, J.A. & Sweeney, J.N. 1991. Intensive shrimp production technology. High Health Aquaculture Inc., Hawaii. 158 pp.

Yang, Y.G., Shariff, M., Lee, L.K. & Hassan, M.D. 2000. Malaysia. *In*: Thematic review on Management Strategies for Major Diseases in Shrimp Aquaculture. A component of the WB/NACA/WWF/FAO Program on Shrimp Farming and the Environment. Report of the workshop held in Cebu, Philippines, 28-30 November 1999. pp. 65-66.

Yu, C.I. & Song, Y.L. 2000. Outbreaks of Taura syndrome in pacific white shrimp *Penaeus vannamei* cultured in Taiwan. *Fish Pathology* 35(1): 21-24.

Annex I – Recommendations on shrimp health management (based on a workshop held in Cebu, Philippines in 1999 (WB/NACA/WWF/FAO, 2001)

Legislation, policy and planning

- Formulate national policies recognizing the importance of shrimp farming as a contributor to national development and assisting its sustainable and responsible development;
- develop improved legal frameworks, monitoring systems and enforcement capabilities to control and register importation and culture of alien shrimp species;
- recognise in legislation the differences between "soft laws", codes and guidelines, and regional or international agreements and WTO "hard laws";
- encourage or enforce farm registration and licensing;
- enforce coastal area management regulations of relevance to shrimp farming;
- critical analysis of approval process for shrimp farms farming alien species;
- legislate penalties for beaches of legislation or quarantine and illegal activities such as smuggling, examine the issue of liability;
- increase interaction between planners, policy makers, industry and other stakeholders to discuss strategies (and their application) for practical approaches to environmentally friendly and sustainable farming of alien shrimp species;
- implement, and if necessary, design, environmental Impact Assessments (EIA) that take account of disease transmission issues with imported species;
- formulate plans for comprehensive shrimp health management strategies using existing and novel approaches to correct problems in the environment, animal and pathogen; and
- develop contingency plans and provide financial, technical and educational assistance for farmers suffering from disease outbreaks.

Regional and international cooperation

- Member states must advise OIE of any outbreaks of listed pathogens;
- begin to regionally harmonize and implement Import Risk Analysis (IRA) to help prevent disease transmission. Training officials in the IRA process should be given priority;
- link national diagnostics and disease control systems with other countries' networks to strengthen regional cooperation;
- establish a regional disease information network/website and a timely disease reporting system;
- organize regional annual meetings and workshops on shrimp health management for dissemination of information;
- establish data base of facilities offering certified disease-free SPF and resistant SPR stocks;

- give priority to collaboration between Latin American and Asian regions for cross-fertilization of ideas; and
- recognize and identify the roles and inputs of NGOs.

Certification, best practice and codes of conduct

- Develop and/or apply "best practices" for management of the shrimp industry based on continuous refinements of the FAO CCRF and similar guidelines on aquaculture development. This should include incorporation of quality assurance programmes (HACCP) into all aspects of the shrimp culture system;
- develop government infrastructure and industry liaison, so that codes of practice can be developed and followed, certifications or accreditations made, expertise in disease control identified and communication and awareness raised for the benefit of both parties;
- there is a slow trend towards eco-labelling and certification of shrimp in international shrimp markets. The environmental advantages of P. vannamei, and particularly its requirement for lower protein use, provide some advantages to this species for an environmental certification or labelling scheme;
- most international Codes of Conduct, as well as new trace-ability requirements from the US and EU will require that shrimp are produced from legal farm operations, therefore, the legal status of P. vannamei farming in a country should be carefully considered, and clarified if necessary; and
- some organic farm certification schemes allow only culture of native species, so the farming of P. vannamei in an Asian country might prevent inclusion in such schemes.

Disease management issues

- Establish national reference pathology labs to inter-calibrate with, and assure the quality of, private disease labs, and collaborate with the existing OIE reference labs;
- initiate Quality assurance programmes, including standardization of techniques and training in disease diagnosis labs to ensure their utility in the control of disease transmission;
- require that all facilities exporting shrimp have a minimum 2 year disease free status, are certified as such and can submit independent, qualified certification of their status;
- submit properly collected samples of imported shrimp to certified disease diagnosis laboratories for assurance of disease-free status, whist maintaining shrimp in biosecure quarantine facilities before release into the environment; and
- conduct co-habitation trials of all imports with indigenous shrimp species to prevent the entry of unknown pathogens that pose high risks to local species.

Research and development

- Fund programmes to investigate methods of combating disease threats (with public/private sector cooperation);
- investigate advantages and disadvantages of alien shrimp for the culture industry of each country to determine its suitability for import;
- Establish closed cycle breeding programmes to produce high quality SPF and SPR seed used for stocking ponds for both alien and indigenous species;

- identify all potential viral pathogens and develop specific and sensitive tools for their detection appropriate for both lab and farmer level;
- research case-specific farming systems for each species so that it can be utilized optimally appropriate to local conditions;
- establish programmes to monitor aquatic environments in and around shrimp farming areas, including effects of culturing new species on wild populations;
- conduct routine analysis on the effects of new viruses on imported and indigenous hosts through cohabitation studies so that any effects or changes of viral pathogenicity can be monitored, and measures for its control investigated;
- conduct routine monitoring of wild shrimp populations for all pathogenic viruses, including an assessment of which species develop the disease and which act as carriers, with attempts made to discover the source of any contamination;
- assess the relative risk factors involved with each potential vector of shrimp pathogens to assist development of more appropriate intervention strategies for disease control;
- evaluate viability of alternative shrimp farming systems (*i.e.* utilizing low-salinity and/or inland farming areas and high density, low impact culture systems);
- investigate shrimp production and health management capabilities and practices to determine suitable codes and guidelines for culture of alien species;
- investigate best methods for dissemination of information pertaining to importation and management of alien shrimp species;
- develop epidemiological approaches to disease management;
- evaluate water treatment methods for their ability to reduce disease risk;
- develop simple, low-cost methods of reducing exposure to disease carriers; and
- Evaluate the effectiveness of green water and shrimp/fish polyculture techniques for reducing disease outbreaks.

Infrastructure, capacity building and training

- Establish a network of collaborating and cross-referencing disease diagnosis laboratories with state of the art equipment and trained manpower;
- consider reinvestment of export profits to improve health management capabilities;
- develop biosecure high-health maturation systems and hatcheries for alien and indigenous species with functional quarantine systems for holding imported animals whilst they are screened, and training facilities/extension for the local farmers;
- develop a programme for the culture and genetic selection of alien and indigenous species to aid development of improved broodstock with desirable culture characteristics, and training of farmers/ extension agents in this technology;
- allocate the necessary equipment, personnel, training and travel required for disease diagnosis, interpretation of test results, and assessment of shrimp health management practices at laboratory and farm level;

- where required, provide overseas training or seminars from experts for government employees, trainers, extension officers and farmers on the techniques required to produce alien species sustainably;
- improve information dissemination and increase farmer awareness of issues involved with the importation and culture of alien shrimp so that farmers have the facts and can clearly understand the potential risks and benefits involved. Collaboration between farmer's associations and the relevant government agencies would assist this process;
- establish databanks on all shrimp farms, perhaps using GIS technology for effective regulation, assessment, monitoring and law enforcement; and
- promote training in the epidemiology of major shrimp diseases to improve awareness and develop practical health management schemes at farm, national and regional levels.

Recent guidelines, code of practice and other instruments

- A recent FAO publication entitled "Health Management and Biosecurity Maintenance in White Shrimp (*Penaeus vannamei*) Hatcheries in Latin America" (FAO 2003) provides information on how to improve health and quality of *P. vannamei* postlarvae produced in hatcheries in Latin America, through improved facility maintenance and husbandry, broodstock maturation, larval rearing, feeding, water quality management, biosecurity, and health management, using interventions at different points of the hatchery production process.
- This document also provides valuable information on how Hazard Analysis Critical Control Points (HACCP) type interventions could be applied during hatchery production of *P. vannamei* postlarvae. The information provided in this document will contribute to the efforts by the *P. vannamei* hatchery operators and mangers in producing quality, disease free, healthy post larvae, thus improving overall production and sustainability of white shrimp aquaculture.
- Major protocols provided in the FAO (2003) document are listed in Annexes II and III.

Annex II – Hatchery guidelines for health management

- Dissemination of information and training in quarantine, maturation and hatchery protocols for alien species are required.
- Biosecurity measures must be implemented for each phase of seed production to maintain high health status.
- Quarantine, maturation and hatchery facilities should be used for only one species to reduce the chances of cross contamination with pathogens.
- Appropriate use of water treatment systems for hatcheries are required in order to remove water-borne sources of contamination (inlet and outlet).
- Biosecure quarantine facilities in which to hold imported or pond-reared broodstock (or PL) during testing for pathogens should become standard.
- The first generation progeny of the introduced animals should be used if they are proven disease free, but not the imported animals themselves, thus imports should be made of broodstock and not nauplii or PL.
- Consideration should be given to the selection of broodstock animals with a wide genetic variation to prevent problems of inbreeding.
- Genetic selection procedures should be based on sound principals aimed at the development of domesticated, fast-growing, disease free (SPF) or disease resistant (SPR) animals adapted for the local conditions.
- Training in rapid diagnostic methods for field use is required.
- Only when live feeds which are proven free from pathogens, or treated suitably to kill them, should they be used.
- Eggs and nauplii from individual spawns should be maintained separate until their health status can be ascertained.
- Both eggs and nauplius should be washed and cleaned using appropriate disinfectants to minimize “vertical” transmission of pathogens from broodstock to larvae.
- Nauplii selection based on their attraction to light should be used to maintain quality.
- High quality feeds (both live and inert) of appropriate quantities should be fed to the larvae to enhance quality and disease resistance.
- Methods of producing larger, high quality PL with which to stock the ponds should be promoted.
- Suitable and reliable methods of PL quality assessment and health screening before transfer to the farm should be promoted.
- The practice of combining tanks with low survival should be discouraged.
- Using a batch system for stocking and harvesting hatchery units with dry out and disinfection time programmed between larval rearing runs should be encouraged.
- When hatchery tanks are drained due to problems, the water and tanks should be treated to kill the larvae and disinfect the tank and water prior to discharge.
- All water discharged from the hatchery should be disinfected before discharge to the environment.

Annex III – Farm guidelines for health management

- Farmers should implement methods for selection of healthy PL for stocking their ponds.
- Methods of water treatment should be analysed for their efficacy in reducing disease risks, reservoirs should be used.
- The use of 160-300 micron screens for all water entering ponds should be promoted as a means of excluding viral carrier organisms from the pond.
- Methods for controlling land and air-based transmission of disease should be investigated.
- Biosecurity measures should be implemented including restricting transfer of equipment and personnel between ponds.
- The risk of disease transfer should be carefully considered before combining shrimp from two or more ponds.
- The stocking of indigenous and alien shrimp species in the same pond, or even farm, should be avoided unless SPF animals of both species are being used.
- Crop rotation, fallowing and dry-out strategies should be considered to reduce problems with transmission of pathogens between cycles.
- Reduced water exchange strategies including stimulation of pond productivity and low protein diets should be encouraged to reduce environmental impacts.
- The utility of “green water” and polyculture of shrimp and fish strategies should be investigated for their abilities to reduce disease occurrence.
- The use of fresh feeds should be discouraged on the farm.
- In the event of emergency harvests, farmers should cooperate by informing their neighbours (possibly sharing costs) and disinfecting any discharges before they effect the environment.
- Research the development of farm-based, real-time diagnostic tests to permit enhanced decision-making at farm level.
- Train pathologists and farmers in use, interpretation, standardization and cross-checking of diagnostic tests.
- Regular dry-out of ponds and farms should be encouraged.
- Where seasonality occurs, risk avoidance strategies during high risk periods should be encouraged.
- Processing plant managers and operators should be informed of the dangers of disposal of untreated wastes into the environment, and encouraged to adopt safe protocols for their disposal.