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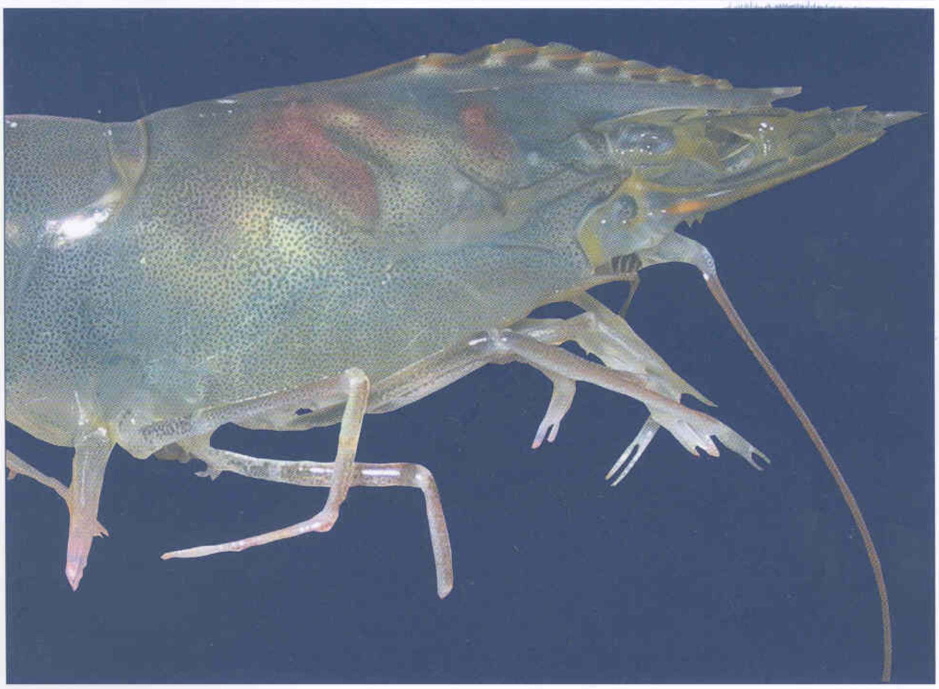
Introductions and movement of *Penaeus vannamei* and *Penaeus stylirostris* in Asia and the Pacific



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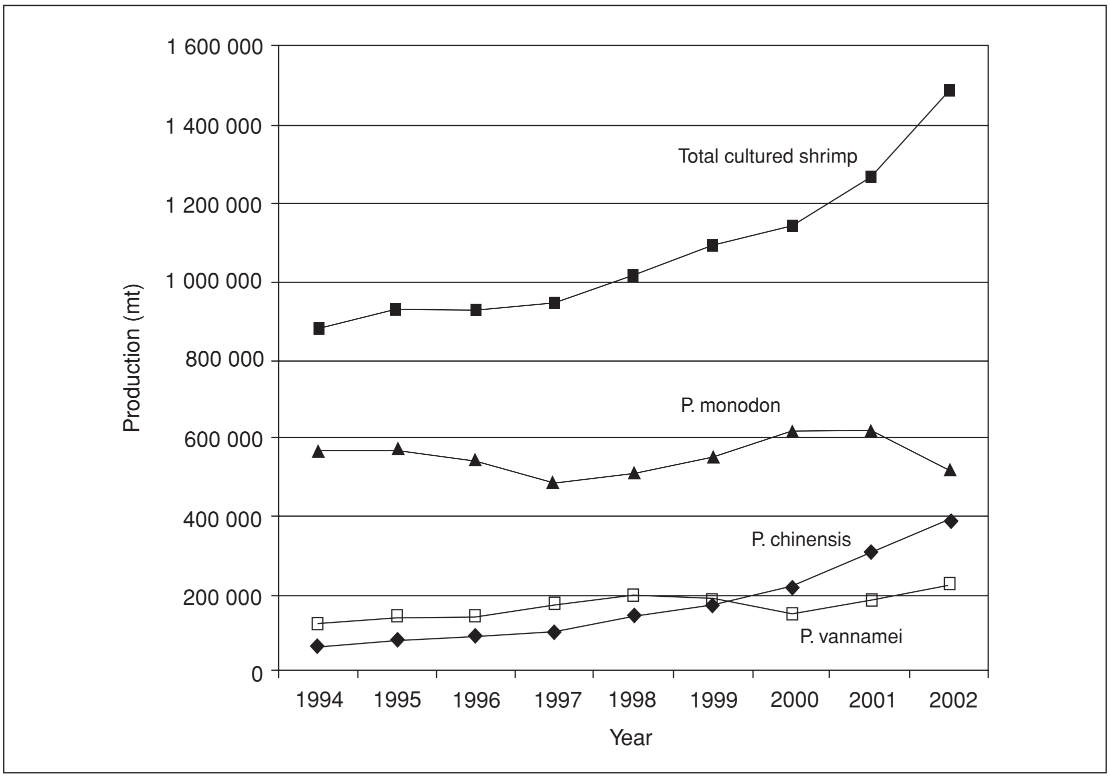
[3] http://www.fao.org/fi/statist/statist.asp

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).

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[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)		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].

[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 3^{rd} and 4^{th} 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.

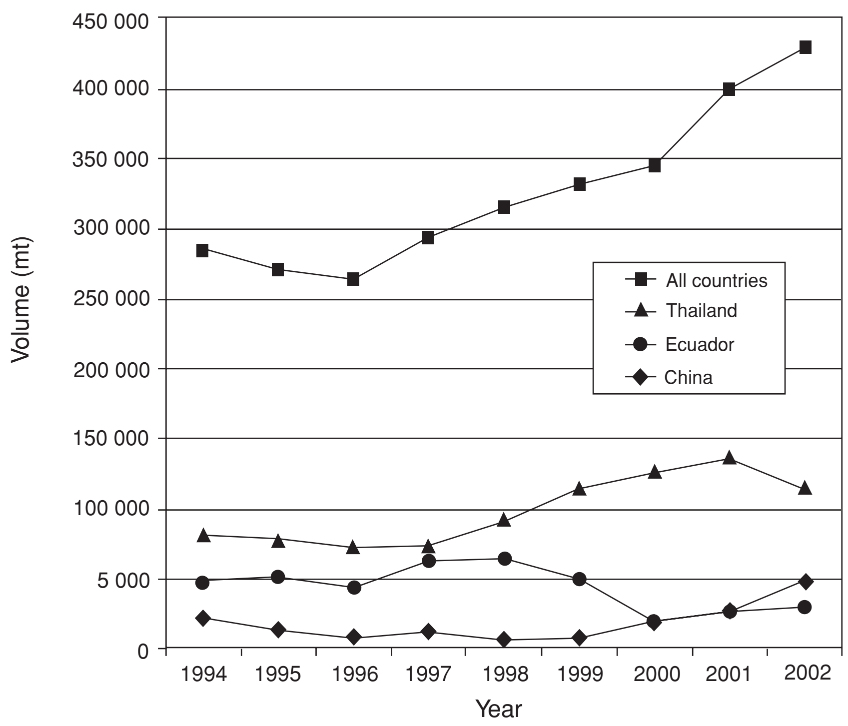
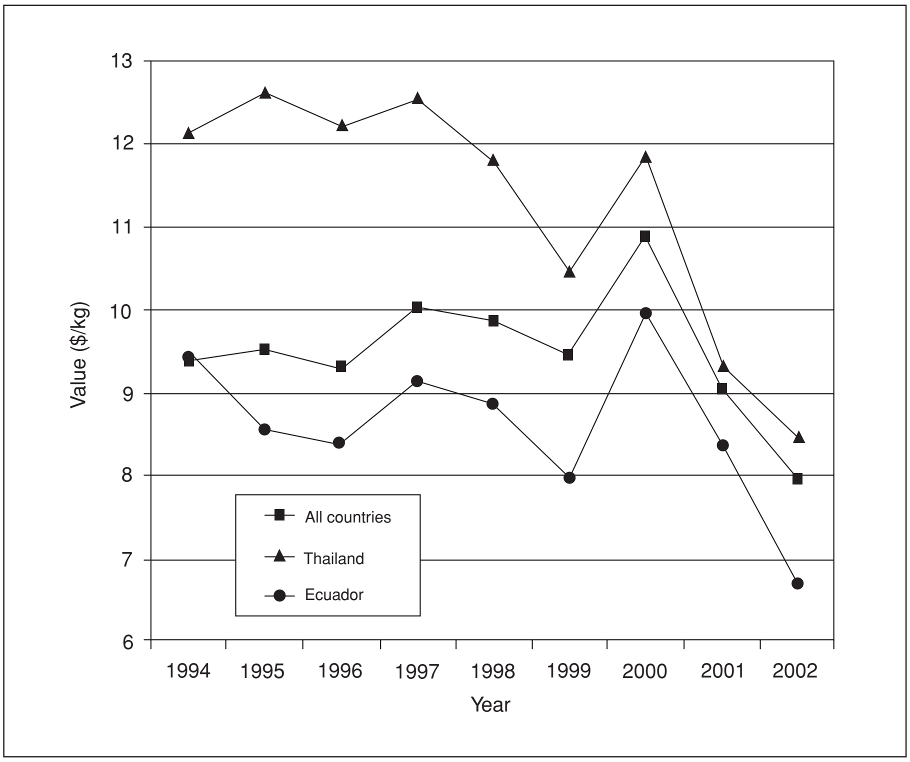


Figure 2: Importation of shrimp to the USA from all and selected countries (1994-2002)

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.