



**AgEcon** SEARCH  
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

*The World's Largest Open Access Agricultural & Applied Economics Digital Library*

**This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.**

**Help ensure our sustainability.**

Give to AgEcon Search

AgEcon Search

<http://ageconsearch.umn.edu>

[aesearch@umn.edu](mailto:aesearch@umn.edu)

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

*No endorsement of AgEcon Search or its fundraising activities by the author(s) of the following work or their employer(s) is intended or implied.*

**Disease Emergence and Food Security: Global Impact of Pathogens on Sustainable  
Aquaculture Production**

**Peter J. Walker  
Professor  
CSIRO**

*Paper prepared for presentation at the “Fish, Aquaculture and Food Security:  
Sustaining Fish as Food Supply” conference conducted by the Crawford Fund for  
International Agricultural Research, Parliament House, Canberra, Australia,  
August 11, 2004*

*Copyright 2004 by Peter J. Walker. All rights reserved. Readers may make verbatim  
copies of this document for non-commercial purposes by any means, provided that this  
copyright notice appears on all such copies.*



# Disease Emergence and Food Security: Global Impact of Pathogens on Sustainable Aquaculture Production

**PETER J. WALKER**

CSIRO Livestock Industries, Australian Animal Health Laboratory (AAHL)  
Private Bag 24, Geelong, Victoria 3220  
Email: Peter.Walker@csiro.au

Aquaculture is one of the most rapidly developing sectors of global food production, contributing significantly to socio-economic development by providing food security and export earnings from high-value products. The importance of the industry to the expanding world population is underscored by the growing gap between supply and demand for seafood. However, rapid growth in aquaculture has been accompanied by increasing problems with disease, and disease is now seen as a very significant threat to sustainable production and trade. During the past decade, disease has devastated prawn farming in Asia and Latin America, with annual losses of up to US\$3 billion. Devastating losses have also hit the salmon farming industries of Europe and North America, the diverse fish farming industries of Japan, Taiwan and China, and shellfish production in Asia and Europe. Disease in aquaculture is the result of ecological disturbances that disrupt the natural balance between pathogens and their host. Farming is often conducted in unnatural habitats which provide opportunities for exposure to new pathogens. Culture conditions may be potentially stressful, causing existing infections to become more severe and precipitate disease outbreaks. Stocking densities are often high,

increasing the risk of disease transmission and spread. There is also a growing trade in live aquatic animals, inevitably resulting in trans-boundary spread of disease and subsequent imposition of trade barriers. Solutions to the growing disease menace lie in improved methods for rapid disease diagnosis and pathogen detection, increased regulation of trans-boundary movement of live aquatic animals, closed-cycle breeding and selection for disease resistance, and improved education and training for both health professionals and farmers.

## Introduction

Aquaculture is one of the most rapidly expanding sectors of global food production. From a relatively low base in the early 1970s, 30 years of technological development, species diversification, commercial investment and government support have fuelled industry growth at an average annual rate of 8.9%. In the year 2000, annual aquaculture production reached 45.7 MMT with a total market value of US\$56.5 billion, representing 32.2% of total fisheries landings and 12.6% of total aquatic and terrestrial meat production (Tacon 2003). Aquaculture is an important source of affordable, high quality, animal protein, especially in the poor communities of developing and low-income food-deficient countries (LIFDCs). Fifty-seven LIFDCs accounted for 83.9% of global aquaculture production in 2000 and, during the past decade, have sustained an annual growth rate over seven times greater than in developing countries (Tacon 2003). The levelling of capture fishery production and growing demands for seafood will drive continued expansion of the aquaculture industry well into this century.

The phenomenal growth in aquaculture production, while beneficial to many poor communities,

PROFESSOR PETER WALKER is Head of Aquaculture and Aquatic Animal Health in CSIRO Livestock Industries, based at the Australian Animal Health Laboratory (AAHL) in Geelong. He also holds an Adjunct Chair in the Centre for Marine Studies at the University of Queensland. He has published more than 75 research papers and book chapters and is a member of the editorial board of several international virology journals. He has worked extensively in Asia and is a regular consultant to FAO and the Network of Aquaculture Centres Asia-Pacific (NACA) on issues relating to aquaculture and fish health management.

has generated changes on a massive scale — changes in land-use, changes in the ecology of aquatic animals, and changes in the patterns of trade. A major consequence of these sociological, ecological and geo-economic changes has been the emergence and spread of disease. Because of disease, aquaculture remains a relatively inefficient and unreliable farming activity, very often operating with poor growth and/or survival rates from seed to harvest, and frequent production failures. Disease is now recognised as one of the most important constraints to efficient and sustainable aquaculture production, impacting on food security, socio-economic development, profitability and trade (Subasinghe and Phillips 2002).

## Ecological balance and disease emergence

There is now a growing understanding of the factors that cause the emergence of new or quiescent infectious diseases that comes from an appreciation of pathogens as an integral part of the ecosystem (Morse 1993, 1995; Brown 1999). The natural biological cycle involves a stable association with one or more hosts, providing the pathogen with a medium for efficient replication and progressive transmission of the infection. As infection proceeds, the pathogen encounters minor variations in its natural environment, including individual variations in host genetics and the immunological response to infection. These challenges are met with compensatory changes by the pathogen, either through ongoing competitive selection of the most suitable mutants or through inherent capacity of pathogens for evasive behaviour. In this way, the pathogen achieves a dynamic equilibrium that sustains a natural ecological balance with its host(s). This equilibrium does not *a priori* require the induction of pathology or disease. Many pathogens infecting humans, animals, plants or fish do not normally cause disease. Indeed, the absence of pathology or mortality frequently provides the pathogen a better opportunity for replication and efficient transmission. Covert infections without disease commonly occur for pathogens that have established a stable ecological niche (Hyatt *et al.* 2004).

New diseases of humans, food animals or wildlife usually emerge as a consequence of a shift in the environment of the pathogen that changes this natural balance and leads to significant changes in the biology of infection (Morse 1993; Daszak *et*

*al.* 2001; Hyatt *et al.* 2004). Such disturbances are usually the result of changes in human activity that have an impact on the ecosystem. Human social and industrial activities that, over the centuries, have been implicated in disease emergence include increased urbanisation, the globalisation of trade, cultural and behavioural changes, the population of new environments, and the establishment and growth of new industries or industrial practices (Brown 1997; Mayer 2000). Changes of this nature can allow the pathogen, through necessity or opportunity, to occupy a new niche in which the ecological balance is temporarily lost (Hyatt *et al.* 2004).

Large-scale aquaculture is such a change in human activity that has provided opportunities for the emergence of an increasing array of diseases. Aquaculture practices remove animals from their natural freshwater, offshore or estuarine environments and place them in high density in sea cages or in terrestrial ponds. This process exposes them to pathogens which they may not naturally encounter, imposes stresses that may compromise their ability to contain infection, and provides ideal conditions for the rapid transmission of infectious agents and disease. Aquaculture has also led to a large and growing trade in live aquatic animals, inevitably resulting in trans-boundary spread of disease (Lightner 1996; Renault 1996; Yoshimitzu 1996).

## Impacts of disease

Disease affects all sectors of aquaculture, but the most dramatic impacts have been seen in prawn farming. Prawn farming is based primarily in developing countries of Asia and Latin America which account for more than 90% of global production. The industry has grown rapidly from a negligible base in the early 1970s to reach a total production volume of 1.48 million metric tonnes (MMT) in 2002 (Tacon 2003). Accompanying this expansion has been a change in land use on a massive scale. Projected from estimates in 1999, about 2 million ha of coastal land globally are now occupied by prawn ponds — an area corresponding to the entire coastal zone of New South Wales or two-thirds the entire coastline of France and extending 10 km inland ([www.greenpeace.org](http://www.greenpeace.org); [www.foodmarketexchange.com](http://www.foodmarketexchange.com)). Predictably, ecological change on this scale has been a catalyst for the emergence and spread of major epizootics of infectious disease. In 1996, a study by C.G.

Lundin commissioned by the World Bank estimated annual disease-related losses in prawn farming globally to be about US\$3000 million or 40% of the production capacity of the industry (Israngkura and Sae-Hae 2002). In China, reported losses of US\$420 million were reported to have occurred in a single season in 1993 (Wei 2002). In Thailand, annual losses peaked at US\$650 million in 1994, falling marginally to US\$600 million in 1997 (T.W. Felgel, *pers. comm.*; Chanratchakool *et al.* 2001). Although there was substantial recovery with the adoption of improved disease management practices, Thai production was again in severe decline by 2002. In India, major disease problems have afflicted the industry since 1984. In 2002, losses in India were evaluated at more than US\$250 million, representing about 60% of the value of national production (K.K. Vijayan, *pers. comm.*). In Indonesia, disease losses were valued at more than US\$300 million in 1999 (Rukyani 2001).

Despite the diverse nature of the prawn farming industry in Asia with respect to the size of farms and the socio-economic status of farmers, most holdings are small farms (<1 ha) operated by low-income families. Lost production due to disease is directly detracting from incomes, job security and food security of these small farmers, as well as from workers in hatcheries, farms, feed mills and processing plants. As prawn aquaculture services seafood markets in the USA, Europe and Japan, disease also directly affects export revenue, with a flow-on of impact on socio-economic development in the sustaining rural communities.

The prawn farming sector has also seen significant environmental impacts of disease. Farms experiencing multiple successive disease outbreaks are often abandoned by well-resourced farmers in favour of new developments elsewhere. Poorer farmers in some Asian countries commonly obtain finance to convert traditional rice fields to potentially more profitable prawn ponds. Successive crop failures result in unrecoverable debt, withdrawal of support from banks and the abandonment of both prawn and rice farming activities. The high prevalence of disease in local prawn stocks in Asia has also driven a major shift in production to exotic species, imported from the Americas. The white Pacific shrimp (*Litopenaeus vannamei*), which is native to the west coast of the Americas from Mexico to Peru, has been bred in captivity for many generations from stocks that are free of most known pathogens. Since 1998–99, *L.*

*vannamei* has been used for large-scale commercial production in Asia, rapidly becoming a major production species and replacing the giant tiger prawn (*Penaeus monodon*) which is native to many parts of Asia (Briggs *et al.* 2004). The white Pacific shrimp is now bred in hatcheries and cultured on-farm in Taiwan, the Chinese mainland, Thailand, Vietnam, Indonesia and elsewhere in the region. It has been estimated that mainland China alone produced 300 000 t of *L. vannamei* in 2003, representing 71% of total production. Throughout Asia, 38% of total production (487 000 t) was estimated to be from this exotic species. The trade in SPF *L. vannamei* from the USA to Asia continues at an estimated rate of 28 000 broodstock per month, translating to a possible 3 billion post-larvae (Briggs *et al.* 2004). This may well represent the largest trans-continental translocation of a single species in history.

The farming of *L. vannamei* in Asia is recognised to have had a positive impact on the reliability of production and a flow-on of socio-economic benefits to poor rural communities. However, the use of translocated broodstock, unscreened or inadequately tested for pathogens, is already known to have led to the spread of disease from the Americas to Asia. Taura syndrome virus (TSV), which first emerged in Ecuador in 1992 and subsequently caused losses estimated at about US\$1.3 billion in the Americas (Brock 1997), is now enzootic in *L. vannamei* in Asia (Tu *et al.* 1999; Yu and Song 2000). There is also evidence of adaptation to TSV infection of local crustaceans, including the major enzootic production species, *Penaeus monodon*. The longer-term impact on disease in Asia and environmental consequences of this mass movement of stock are not yet fully appreciated.

It is now widely recognised that trans-boundary movement of live aquatic animals is the major cause of the spread of aquatic pathogens and diseases. International trade in aquaculture seed and the movement of stock within national borders are intrinsic to the structure of the industry in many parts of the world. Pathogens are often present at very low levels in apparently healthy animals, escaping detection. Disease may only emerge following translocation when the pathogens are activated by stressful conditions of transportation or culture. To prevent the spread of pathogens there has been an increasing reliance on trade restrictions, often implemented without reference to the internationally agreed procedures and protocols instituted in the Sanitary and Phyto-Sanitary (SPS) Agreement

of the World Trade Organization that are intended to promote free trade.

Although less dramatic in impact, other aquaculture sectors also face serious disease issues. The salmon-farming industries of Europe and North America suffered serious losses following the emergence and spread of infectious salmon anaemia (ISA) in 1984. By 1999, the ISA epizootic was estimated to have cost the industries of Norway, Scotland and Canada in the order of US\$60 million (Anon. 1999; Hastings *et al.* 1999). Fish farming in Asia is plagued by production losses caused primarily by epizootic ulcerative syndrome (EUS) and highly pathogenic nodavirus and iridovirus infections. Studies conducted in Bangladesh, India, Vietnam, Philippines and Indonesia indicated that EUS (or red spot disease) is widespread and impacting significantly on small-scale farmer income and food supply. In Thailand, it is estimated that economic loss due to EUS has totalled US\$100 million since 1993 (Anon. NACA Disease Library [www.enaca.org](http://www.enaca.org)). In Bangladesh, fish prices at market fell by 60–75% following the first EUS outbreak in 1989, and 89% of farmers surveyed in 1998 considered EUS a major production problem (Lilley *et al.* 2002). In Vietnam, EUS is considered the major constraint to improving output from freshwater culture, primarily carp and tilapia (Van *et al.* 2002). A study of small-scale sea bass and grouper farmers in Thailand indicated that, on average, they faced 30–40% mortality per crop (Kanchanakhan *et al.* 2002). Widespread disease problems are also facing the rapidly-growing shellfish industry in East and South-east Asia. It has been estimated that, in China alone, the annual economic loss due to disease in aquaculture is US\$1.2 billion (Wei 2002).

## **A case study of disease emergence and spread**

White spot syndrome virus (WSSV) is the most devastating of prawn pathogens, responsible for direct production losses likely to total more than US\$10 billion over the past decade. WSSV is not a natural pathogen of prawns. The disease first emerged in 1992 from an unknown source in eastern China, apparently as a unique event, and it has since spread to most prawn farming regions of the world. The WSSV original outbreak occurred in a few ponds of kuruma prawns (*Marsupenaeus japonicus*) at Zhangpu in Fujian Province (Zhan *et al.* 1998; Lo *et al.* in press), and subsequently

spread inland and along the coast as ponds were stocked with infected seed. During 1993, there was a rapid and progressive spread of the disease in other cultured prawn species along the Chinese coast to Shandong, Hebei and other provinces (Zheng, *pers. comm.*). In 1992, the disease was also first reported in northern Taiwan in domesticated kuruma prawns introduced from the mainland (Chou *et al.* 1995; Wang *et al.* 1996, Lo *et al.* in press). From March 1993, WSSV appeared in cultured kuruma prawns in Japan (Nakano *et al.* 1994). Initially, the disease affected all farms in five Prefectures that had imported juveniles from China. The disease then spread to other farms in Japan. In 1993, WSSV was also detected on the southern and western coasts of Korea (Park *et al.* 1998).

The first recorded observation of white spot syndrome outside East Asia appears to have been in India in early 1993, but the outbreak was not regarded as serious at the time (Rajendran and Vijayan 2000). The first serious epizootic commenced in November–December 1994 in Nellore, Andhra Pradesh on the east coast of the sub-continent (Mohan *et al.* 1998). On the Indian west coast, the first recorded outbreak commenced in the North Canara district of Karnataka in July 1995 (Karunsagar *et al.* 1997). The initial outbreaks have subsequently spread to all farming regions of India. In Thailand, WSSV was first detected in laboratory-reared giant tiger prawns during a transmission trial for yellow head virus in late 1993. White spot disease was not reported in farmed prawns in Thailand until late 1994 (Flegel 1997). The disease was first observed in the south but subsequently spread to all prawn farming regions of the country.

WSSV has also now been reported in most prawn-farming economies of Asia including Indonesia, Malaysia, Sri Lanka, Myanmar, Bangladesh and Vietnam. Despite the proximity to the infected industries of other Asian countries, the Philippines remained free of WSSV until 1999, probably due to restrictions on the importation of broodstock, nauplii and post-larvae. Australian prawn farms are free of WSSV infection but it is considered a major exotic disease threat. The absence of WSSV in Australian prawns has been attributed to the prohibition on importation of live crustaceans and uncooked bait prawns.

The first recorded outbreak of white spot syndrome in the Western hemisphere occurred in a

single pond in Texas, USA, in November 1995. A nearby prawn reprocessing plant that imported heads-on frozen prawn from Asia was assumed to be the source (Lightner *et al.* 1997). In 1996 and 1997, WSSV was detected and associated with severe mortalities in crayfish at the National Zoo in Washington DC. The crayfish had been fed routinely with imported frozen prawn. In 1997, WSSV was detected in captive prawns in a research facility in Texas. In 1997 and 1998, WSSV was detected in wild prawn stocks from South Carolina and in bait prawns in Texas.

The major epizootic of white spot disease in the Western Hemisphere commenced on the Pacific coast of Central America in 1999. The first report was from samples collected in Nicaragua, Honduras and Guatemala in mid-January following mortalities in some ponds. Subsequently, the disease was reported in Panama in March, Ecuador in May and had reached Peru by October (Alday de Graindorge 2000a). It is now enzootic in all prawn farming regions on the Pacific coast from Mexico to Peru. Retrospective testing has indicated that WSSV was present in samples collected in Ecuador from 1996 to 1998, prior to the first disease outbreaks (Alday de Graindorge 2000b). It is likely that the virus existed as a covert infection in healthy wild prawns well before disease occurred on farms. The concurrence of the initial widespread outbreaks with the aftermath of Hurricane Mitch suggest the widespread environmental disturbance may have precipitated the American epizootic. The route by which WSSV was introduced to Latin America remains unclear.

## Conclusion

The devastating white spot pandemic and other major disease outbreaks impacting on food security have been catalysts for profound changes in the structure and operation of the aquaculture industry, and have led governments to address more seriously the issue of aquatic animal disease management. The messages have been clear. Disease emergence and spread are not simply unfortunate natural disasters that are beyond our control. They are a predictable consequence of the massive sociological, ecological and geo-economic changes that have accompanied the development of this new industry. As aquaculture continues to expand, evolve and diversify, new diseases will emerge and, if we are not adequately prepared, the consequences will be devastating for food security,

socio-economic development and trade. The vast potential for aquaculture development in Africa remains relatively untapped, but will surely be the source of new disease challenges. To meet the challenge of containing disease and ensuring efficient and sustainable aquaculture production, we must continue to improve our understanding of aquatic animal pathogens and our diagnostic capabilities, improve disease surveillance and emergency response capabilities, improve the regulation of trans-boundary movement of aquatic animals and other high-risk commodities, and develop improved technologies for low-cost, chemical-free treatments and disease resistance. To ensure food security at the level of small-scale farmers, we must also improve education and training in practical disease management practices that are effective and affordable at the subsistence level.

## References

- Alday de Graindorge, V. 2000a. Disease management protocols and semi-intensive shrimp farming in Ecuador. *Global Aquaculture Advocate* 3(2), 17–19.
- Alday de Graindorge, V. 2000b. The white spot syndrome virus is not new in Ecuador. *Global Aquaculture Advocate* 3(1), 17.
- Anon. 1999. *Salmon Farming and the Impact of the ISA Virus*. The Scottish Parliament Information Centre. Research Note 99/20.
- Briggs, M., Funge-Smith, D., Subasinghe, R. and Phillips, M. 2004. *Introductions and Movement of Penaeus vannamei and Penaeus stylirostris in Asia and the Pacific*. FAO, Bangkok, 92 pp.
- Brock, J.A. 1997. Special topic review: Taura syndrome, a disease important to shrimp farms in the Americas. *World Journal of Microbiology and Biotechnology* 13, 415–418.
- Brown, C. 1997. Emerging diseases — what veterinarians need to know. *Journal of Veterinary Diagnostic Investigation* 9, 113–117.
- Brown, C. 1999. Emerging diseases of animals. In: Scheld, W.M., Craig, W.A. and Hughes, J.M. *Emerging Infections 3*, ASM Press, Washington DC, USA, pp. 153–163.
- Chanratchakool, P., Fegan, D.F. and Phillips, M.J. 2001. *Thailand: Thematic Review on Management Strategies for Major Diseases in Shrimp Aquaculture*. A component of the WB/NACA/WWF/FAO Program on Shrimp Farming and the Environment. Report of the workshop held in Cebu, Philippines, 28–30 November 1999. 135 pp.

- Chou, Y.H., Huang, C.Y., Wang, C.H., Chiang, H.C. and Lo, C.F. 1995. Pathogenicity of a baculovirus infection causing white spot syndrome in cultured shrimp in Taiwan. *Diseases of Aquatic Organisms* **23**, 165–173.
- Daszak, P., Cunningham, A.A. and Hyatt, A.D. 2001. Anthropogenic environmental change and the emergence of infectious diseases in wildlife. *Acta Tropica* **78**, 103–116.
- Flegel, T.W. 1997. Major viral diseases of black tiger prawn (*Penaeus monodon*) in Thailand. *World Journal of Microbiology and Biotechnology* **13**, 433–442.
- Hastings, T., Olivier, G., Cusak, R., Bricknell, I., Nylund, A., Binde, M., Munro, P. and Allan, C. 1999. Infectious salmon anaemia. *Bulletin of the European Association of Fish Pathologists* **19**, 286–288.
- Hyatt, A.D., Daszak, P., Cunningham, A.A., Field, H. and Gould, A.R. 2004. Henipaviruses: gaps in the knowledge of emergence. *EcoHealth* **1**, 25–38.
- Israngkura, A. and Sae-Hae, S. 2002. A review of economic impacts of aquatic animal disease. In: Arthur, J.R., Phillips, M.J., Subasinghe, R.P., Reantaso, M.B. and McCrae, I.H. (eds) *Primary Aquatic Animal Health Care in Rural, Small-Scale Aquaculture Development*. Technical proceedings of the Asia regional scoping workshop, Dhaka, Bangladesh, 27–30 September 1999. FAO Fisheries Technical Paper 406. FAO, Rome, pp. 253–286.
- Kanchanakhan, S., Chanratchakool, P. and Direkbusarakom, S. 2002. The impact of disease on small-scale coastal cage-fish culture in Thailand. In: Arthur, J.R., Phillips, M.J., Subasinghe, R.P., Reantaso, M.B. and MacRae, I.H. (eds) *Primary Aquatic Animal Health Care in Rural, Small-Scale Aquaculture Development*. Technical proceedings of the Asia regional scoping workshop, Dhaka, Bangladesh, 27–30 September 1999. FAO Fisheries Technical Paper No. 406, pp. 203–206.
- Karunsagar, I., Otta, S.K. and Karunsagar, I. 1997. Histopathological and bacteriological study of white spot syndrome of *Penaeus monodon* along the west coast of India. *Aquaculture* **153**, 9–13.
- Lightner, D.V. 1996. Epizootiology, distribution and the impact on international trade of two penaeid shrimp viruses in the Americas. *Revue Scientifique et Technique Office International des Epizooties* **15**, 579–602.
- Lightner, D.V., Redman, R.M., Poulos, B.T., Nunan, L.M., Mari, J.L. and Hasson, K.W. 1997. Risk of spread of penaeid shrimp viruses in the Americas by international movement of live and frozen shrimp. *Revue Scientifique et Technique Office International des Epizooties* **16**, 146–160.
- Lilley, J.H., Callinan, R.B. and Khan, M.H. 2002. Social, economic and biodiversity impacts of epizootic ulcerative syndrome (EUS). In: Arthur, J.R., Phillips, M.J., Subasinghe, R.P., Reantaso, M.B. and MacRae, I.H. (eds) *Primary Aquatic Animal Health Care in Rural, Small-Scale Aquaculture Development*. Technical proceedings of the Asia regional scoping workshop, Dhaka, Bangladesh, 27–30 September 1999. FAO Fisheries Technical Paper No. 406, pp. 127–139.
- Lo, C.F., Peng, S.E., Chang, Y.S. and Kou, G.H. (in press). White spot syndrome — what we have learned about the virus and the disease. In: Walker, P.J., Lester, R.J. and Reantaso, M.B. (eds) *Diseases in Asian Aquaculture V*. Proceedings of the Fifth Symposium on Diseases in Asian Aquaculture. Gold Coast, Australia, 24–28 November, 2002. Asian Fisheries Society, Manilla.
- Mayer, J.D. 2000. Geography, ecology and emerging infectious diseases. *Social Science and Medicine* **50**, 937–952.
- Mohan, C.V., Shankar, K.M., Kulkarni, S. and Shdha, P.M. 1998. Histopathology of cultured shrimp showing gross signs of yellow head syndrome and white spot syndrome during 1994 Indian epizootics. *Diseases of Aquatic Organisms* **34**, 9–12.
- Morse, S.S. (ed.) 1993. *Emerging Viruses*. Oxford University Press, New York, USA, 317 pp.
- Morse, S.S. 1995. Factors in the emergence of infectious diseases. *Emerging Infectious Diseases* **1**, 7–15.
- Nakano, H., Koube H., Umezawa, S., Momoyama, K., Hiraoka, M., Inouye, K. and Oseko, N. 1994. Mass mortalities of cultured kuruma shrimp, *Penaeus japonicus*, in Japan in 1993: Epizootological survey and infection trials. *Fish Pathology* **29**, 135–139.
- Park, J.H., Lee, J.S., Lee, S. and Lee, Y. 1998. An infectious viral disease of penaeid shrimp newly found in Korea. *Diseases of Aquatic Organisms* **34**, 71–75.
- Rajendran, K.V. and Vijayan, K.K. 2000. WSSV in India. *Global Aquaculture Advocate* **3**(2), 76–77.
- Renault, T. 1996. Appearance and spread of diseases among bivalve molluscs in the northern hemisphere in relation to international trade. *Revue Scientifique et Technique Office International des Epizooties* **15**, 551–562.
- Rukyani, A. 2001. Indonesia. In: *Thematic Review on Management Strategies for Major Diseases in Shrimp Aquaculture*. A component of the WB/NACA/WWF/FAO Program on Shrimp Farming and the Environment. Report of the workshop held in Cebu, Philippines, 28–30 November 1999, pp. 59–64.
- Subasinghe, R.P. and Phillips, M.J. 2002. Aquatic animal health management: opportunities and challenges for rural, small-scale aquaculture and enhanced-fisheries development: Workshop introductory re-

- marks. In: Arthur, J.R., Phillips, M.J., Subasinghe, R.P., Reantaso, M.B. and MacRae, I.H. (eds) *Primary Aquatic Animal Health Care in Rural, Small-Scale Aquaculture Development*. FAO Fisheries Technical Paper No. 406, pp. 1–5.
- Tacon, A.J. 2003. Aquaculture production trend analysis. In: *Review of the State of World Aquaculture*. FAO Fisheries Circular No. 886, pp. 5–29.
- Tu, C., Huang, H.T., Chuang, S.H., Hsu, J.P. Kuo, S.T., Li, N.J., Hsu, T.L., Li, M.C. and Lin, S.Y. 1999. Taura syndrome in Pacific white shrimp *Penaeus vannamei* cultured in Taiwan. *Diseases of Aquatic Organisms* **38**, 159–161.
- Van, P.T., Khoa, L.V., Lua, D.T., Van, K.V. and Ha, N.T. 2002. The impacts of red spot disease on small-scale aquaculture in northern Vietnam. In: Arthur, J.R., Phillips, M.J., Subasinghe, R.P., Reantaso, M.B. and MacRae, I.H. (eds) *Primary Aquatic Animal Health Care in Rural, Small-Scale Aquaculture Development*. FAO Fisheries Technical Paper No. 406, pp. 165–176.
- Wang, C.S., Tang, K.F.J., Kou, G.H. and Chen, S.N. 1996. Yellow head disease-like virus infection in the kuruma shrimp *Penaeus japonicus* in Taiwan. *Fish Pathology* **31**, 177–182.
- Wei, Q. 2002. Social and economic impacts of aquatic animal health problems in aquaculture in China. In: Arthur, J.R., Phillips, M.J., Subasinghe, R.P., Reantaso, M.B. and MacRae, I.H. (eds) *Primary Aquatic Animal Health Care in Rural, Small-Scale Aquaculture Development*. FAO Fisheries Technical Paper No. 406, pp. 55–61.
- Yoshimitzu, M. 1996. Disease problems of salmonid fish in Japan caused by international trade. *Revue Scientifique et Technique Office International des Epizooties* **15**, 533–550.
- Yu, C.I. and Song, Y.L. 2000. Outbreaks of Taura syndrome in pacific white shrimp *Penaeus vannamei* cultured in Taiwan. *Fish Pathology* **35**, 21–24.
- Zhan, W.B., Wang, Y.H., Fryer, J.L., Yu, K.K., Fukuda, H. and Meng, Q.X. 1998. White spot syndrome virus infection of cultured shrimp in China. *Journal of Aquatic Animal Health* **10**, 405–410.