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Disease and health management in Asian aquaculture[☆]

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Abstract

Asia contributes more than 90% to the world's aquaculture production. Like other farming systems, aquaculture is plagued with disease problems resulting from its intensification and commercialization. This paper describes the various factors, providing specific examples, which have contributed to the current disease problems faced by what is now the fastest growing food-producing sector globally. These include increased globalization of trade and markets; the intensification of fish-farming practices through the movement of broodstock, postlarvae, fry and fingerlings; the introduction of new species for aquaculture development; the expansion of the ornamental fish trade; the enhancement of marine and coastal areas through the stocking of aquatic animals raised in hatcheries; the unanticipated interactions between cultured and wild populations of aquatic animals; poor or lack of effective biosecurity measures; slow awareness on emerging diseases; the misunderstanding and misuse of specific pathogen free (SPF) stocks; climate change; other human-mediated movements of aquaculture commodities. Data on the socio-economic impacts of aquatic animal diseases are also presented, including estimates of losses in production, direct and indirect income and employment, market access or share of investment, and consumer confidence; food availability; industry failures. Examples of costs of investment in aquatic animal health-related activities, including national strategies, research, surveillance, control and other health management programmes are also provided. Finally, the strategies currently being implemented in the Asian region to deal with transboundary diseases affecting the aquaculture sector are highlighted. These include compliance with international codes, and development and implementation of regional guidelines and national aquatic animal health strategies; new diagnostic and therapeutic techniques and new information technology; new biosecurity measures including risk analysis, epidemiology, surveillance, reporting and planning for emergency response to epizootics; targeted

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research; institutional strengthening and manpower development (education, training and extension research and diagnostic services).

Keywords: Aquaculture; Parasite disease; Production loss; Disease management

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1. Introduction

“Aquaculture is the farming of aquatic organisms including fish, molluscs, crustaceans and aquatic plants. Farming implies some sort of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc.” (Code of Conduct for Responsible Fisheries of the Food and Agriculture Organization (FAO) of the United Nations; FAO, 1995).

Aquaculture has a long history. In the People’s Republic of China (PR China), common carp were raised for food in freshwater ponds as early as 1100 B.C., while oyster farming was recorded as early as the Han Dynasty (206 B.C.–220 A.D.) (Hishamunda and Subasinghe, 2003). Other examples of early aquaculture practices include the Japanese culturing oysters for pearls; ancient Egyptians stocking ponds with fish; the Greeks and Romans raising eels; the Europeans cultivating oysters.

Today, aquaculture is the fastest growing food-producing sector in the world, with an average annual growth rate of 8.9% since 1970, compared to only 1.2% for capture fisheries and 2.8% for terrestrial farmed meat production systems over the same period. The most recent statistics indicate that the sector reached aquatic production of 9.4% annual percentage growth rate (APR) compared with meat production of farmed terrestrial animals such as pigs (APR of 3.1%), poultry (APR 5.1%), beef and meal (APR 1.2%), and mutton and lamb (APR 1.0%) (FAO, 2004). The per capita supply from aquaculture increased from 0.7 kg in 1970 to 6.4 kg in 2002, giving an annual growth rate of 7.2%. In 2002, the total world aquaculture production (including aquatic plants) was reported to be 51.4 million tonnes by volume and US$ 60.0 billion by value. This represents an annual increase of 6.1% in volume and 2.9% in value, respectively, over reported figures for 2000. Asia produced 91.2% (by volume) and 82.0% (by value) of global aquaculture production. Of the world total, the PR China produced 71.2% of the total volume and 54.7% of the total value of aquaculture production. In 2002, the other nine top producers were India, Indonesia, Japan, Bangladesh, Thailand, Norway, Chile, Vietnam and the United States of America (Crespi, 2005). The majority of aquaculture production of fish, crustaceans and molluscs continues to come from the freshwater environment (57.7% by volume and 48.4% by value). Mariculture contributes 36.5% of production and 35.7% of the total value. Although brackishwater production represented only 5.8% of production volume in 2002, it contributed 15.9% of the total value, reflecting the prominence of high-value crustaceans and finfish (FAO, 2004).

The aquaculture sector is highly diverse (Subasinghe, in preparation; NACA/FAO, 2001; De Silva, 2001; Funge-Smith and Phillips, 2001) in terms of:

(a) *Species*—an estimated 230 species of finfish, molluscs, crustaceans, aquatic plants, turtles, frogs, etc. are cultured.
(b) *Culture systems*—e.g., water-based systems, such as cages and pens, bottom/pole/rack/raft/long-line systems for molluscs, inshore and off-shore; land-based systems such as rain-fed ponds; irrigated or flow-through systems, tanks and raceways; land/water-based systems, such as sea ranching; recycling systems such as high control enclosed systems, more open pond-based recirculation; monoculture and polyculture systems; integrated farming systems, such as livestock-fish, integrated agriculture-aquaculture, livestock-aquaculture.
(c) *Culture environment*—e.g., freshwater, brackish water, marine; inland, coastal and oceanic; temperate to tropical.
(d) *Type of operation and scale*—e.g., small-scale backyard ponds and hatcheries to commercial operations; hatchery holding of broodstock and production of seed, nursing systems, grow-out.
(e) *Intensity of practice*—e.g., extensive, semi-intensive, intensive.

(f) *Type of management*—from family to corporate ownership.

Aquaculture is a significant socio-economic activity, especially for rural communities, contributing to livelihoods, food security and poverty alleviation through such mechanisms as income generation, employment, services, use of local resources, diversified farming practices, domestic and international trade and other economic investments serving the sector (NACA/FAO, 2001; Edwards et al., 2002).

Tacon (2001) pointed out that ''food fish'' has a nutritional profile superior to all terrestrial meat, being an excellent source of high quality animal protein and highly digestible energy, as well as an extremely rich source of omega-3 polyunsaturated fatty acids (PUFAs)l, fat-soluble vitamins (A, D and E) and water-soluble vitamins (B complex) and minerals (calcium, phosphorus, iron, iodine and selenium). At present, ''food fish'' represents the primary source of animal protein (contributing more than 25% of the total animal protein supply) for about one billion people within 58 countries worldwide, including many developing countries and low-income food-deficit countries (LIFDCs) (value excludes China). Consumption of omega-3 fatty acids from seafood products (including those from aquaculture) has been shown to prevent or ameliorate certain types of diseases (e.g., coronary heart disease and stroke; autoimmune disorders; cancers of the breast, colon and prostate; hypertension and rheumatoid arthritis) (Flick, 2004).

Taking into consideration the global population growth, it is clear that the future demand for aquatic products, even at the current level of per capita consumption, cannot be supplied by capture fisheries and therefore, the bulk will have to come from aquaculture. This goal will face considerable challenges, including management of aquatic animal health, which is already one of the major constraints to the development and expansion of the sector.

2. Health as a constraint to aquaculture

The current trend in aquaculture development is towards increased intensification and commercialization of aquatic production. Like other farming sectors, the likelihood of major disease problems occurring increases as aquaculture activities intensify and expand. Thus, the aquaculture industry has been overwhelmed with its share of diseases and problems caused by viruses, bacteria, fungi, parasites and other undiagnosed and emerging pathogens. Disease is now a primary constraint to the culture of many aquatic species, impeding both economic and social development in many countries. This situation can be attributed to a variety of multi-faceted and highly interconnected factors such as the increased globalization of trade in live aquatic animals and their products; the intensification of aquaculture through the translocation of broodstock, postlarvae, fry and fingerlings; the development and expansion of the ornamental fish trade (Subasinghe et al., 2001); the enhancement of marine and coastal areas through stocking aquatic animals raised in hatcheries (Bartley et al., submitted for publication); the misunderstanding and misuse of specific pathogen free (SPF) stocks (e.g. shrimps); unanticipated negative interactions between cultured and wild fish populations (Olivier, 2002); poor or lack of effective biosecurity measures; slow awareness on emerging diseases; climate change; all other human mediated movements of aquaculture commodities.

A few examples of parasite translocations with host movements are provided below. The study of Lumanlan et al. (1992) revealed that imported fishes entering the Philippines are infected with potentially pathogenic parasites of the protozoan genera *Trichodina*, *Ichthyophthirius*, *Cryptobia*, *Icthyobodo*, and *Trypanosoma*; the monogenean genera *Dactylogyrus* and *Gyrodactylus*; the digenean *Ascocotyle*; the cestode *Bothriocephalus* and the crustaceans *Lernaea* and *Argulus*. In other studies, Natividad et al. (1986) and Bondad-Reantaso and Arthur (1989, 1990) found that at least 14 species of exotic parasites have been transferred into and become established in the Philippines along with the importation of Nile tilapia (*Oreochromis niloticus*) and Chinese carps. In Indonesia, the introduction of *Lernaea cyprinacea* in 1971 and *Myxobolus* sp. in 1974 with imported fishes caused great losses to farmers (Djajadiredja et al., 1983). *Neobenedenia girellae* is one of the most commonly reported monogenean parasites of grouper (*Epinephelus* spp.) and other marine fishes. This parasite was introduced to Japan along with importation of amberjack fry (*Seriola dumerili*) from Hainan and Hong Kong, China. This monogenean caused heavy infection among flounder cultured in floating netcages in 1991 and of one-year-old amberjack in 1992 in Japan, where a total of 15 cultured marine fishes (e.g. groupers and flounders, *Paralichthys olivaceus*) and brackishwater cultured tilapia are susceptible (Ogawa et al., 1995). *N. girellae* now causes serious problems in grouper culture in most countries of Southeast Asia (Bondad-Reantaso et al., 2001a,b).

The molluscan parasite *Bonamia ostreae* was introduced into Europe by means of imports of infected juveniles of flat oyster, *Ostrea edulis*, from California (Grizel, 1997; Cigarría and Elston, 1997). The pathogen rapidly spread to almost the entire oyster farming areas in Europe. In the southern hemisphere, bonamiosis caused by *B. exitiosa* was most probably transferred via movements of infected oysters, *Ostrea chilensis*, intended for human consumption from New Zealand into Tasmania (Dartnall, 1969).

The Pacific oyster, *Crassostrea gigas*, was introduced from Matsushima Bay in Japan to the west coast of the United States, and from there moved to the east coast. These western United States stocks are infected at low levels with the parasite *Haplosporidium* sp. (identical to *Haplosporidium nelsoni*), which has caused massive mortalities among eastern oysters (*C. virginica*) along the eastern coast of the United States. A highly specific and sensitive DNA probe, developed to detect *H. nelsoni* by in situ hybridization, also detects the *Haplosporidium* sp. described in Pacific oysters of the western United States and Matsushima Bay (Burresson et al., 2000). It is now known that *H. nelsoni* is present in *C. gigas* in Japan (Kamaishi and Yoshinaga, 2002) and Korea (Kern, 1976). It thus appears that *H. nelsoni* does not cause serious disease in Pacific oysters, and it is speculated that this pathogen was introduced into the Pacific coast of the United States through the movement of apparently healthy, but infected, *C. gigas*. Infected Pacific oysters were then introduced onto the eastern United States, where the parasite proved highly virulent to a new host (Burresson et al., 2000), infecting eastern oysters and causing mass mortalities. This example demonstrates the possible dramatic and unpredictable consequences of transferring infected stocks.

Interactions between wild and cultured fish populations are an important concern for both aquaculturists and natural resource conservation officers. Disease is a result of the complex interaction between the host, the pathogen and the environment (Snieszko, 1974). In order for a disease to spread from either cultured fish to wild fish or vice-versa, certain criteria as described by Olivier (2002) are essential:

- presence of pathogen in both fish and water source;
- presence of susceptible host;
- viability, in terms of number and longevity, of pathogen in the environment;
- viable infection route.

However, once a pathogen or disease agent is introduced and becomes established into the natural environment, there is little or no possibility for either treatment or eradication. While consequences of ‘‘trickle’’ infections from wild to cultured populations have predictable consequences due to accessible hosts under cultured conditions, the consequences of culture-borne transmission to wild stocks are harder to predict. Examples of infection of cultured stocks via wild stock reservoirs for shrimp diseases have been described by Flegel and Alday-Sanz (1997), Ruangsiri and Supamattaya (1999), Rajendran et al. (1999) and Dixon (1999) for marine finfish disease. Koi herpes virus (KHV) has recently been introduced to Indonesia and Japan. In Japan, it has caused mass mortalities not only among farmed carp but also wild carp in many rivers and lakes. Additional examples from Japan include the following:

- *Neoheterobothrium hirame*, a monogenean parasite, the original host probably being southern flounder from the United States, is believed to have been the cause of a decline in the catch of olive flounder in some parts of Japan (Anshary et al., 2002);
- White spot syndrome virus (WSSV) remains an important pathogen of farmed shrimp (*Penaeus monodon*) and has now been recovered from wild penaeid shrimps.

The KHV incursion is a good example of an infection which initially spread from a cultured ornamental fish (koi carp) to cultured foodfish (common carp) and then into wild populations of carp. This clearly shows that cultured fish can be a source of major disease transfer to wild populations, a risk that the aquaculture industry (e.g. salmon culture) has tried to down play in the past.

According to Briggs et al. (2004), beginning in 2000, importation of specific pathogen free (SPF) stocks, for example, the ‘‘super shrimp’’ *Litopenaeus stylirostris*, has been carried out by Asian countries (e.g. Brunei Darussalam, Taiwan Province of China, Myanmar, Indonesia and Singapore) from secure breeding facilities in Mexico and the United States. Taura syndrome (TS), another serious viral disease of shrimp affecting *L. stylirostris,* has now been detected in Indonesia, Thailand, Vietnam and Taiwan Province of China in cultured *L. vannamei* (de la Peña, 2004; Sunarto et al., 2004; Van, 2004; Arthur, 2005). The concept of SPF is generally poorly understood (Carr, 1996; Lotz, 1997). Once broodstock or postlarvae produced by an SPF facility leave that facility, they are no longer considered to have an SPF status for the specific pathogens indicated, since the level of biosecurity under which they are being maintained has now decreased. Because their health status is now less certain, a new historical record for that facility must be established to support any claims of health status.

Climatic changes also contribute to conditions favouring disease outbreaks. Classical examples are the outbreaks of *H. nelsoni* and *Perkinsus marinus* (both oyster parasites, also commonly known as MSX and dermo disease, respectively) affecting oysters in Chesapeake Bay in the United States. Harvell et al. (1999) reported that the El Niño occurrence was correlated with Mexican oyster pathogen outbreak and range extension of other oyster pathogens in New England.

The shrimp viral disease epidemics are classical examples of the range and distance that aquatic animal pathogens can travel alongside the movement of their hosts. One shrimp viral disease alone, white spot disease (WSD) remains the most serious pathogen of cultivated shrimp in the world. The Asian pandemic occurred in the 1990s, affecting many shrimp-producing countries in Asia (Bangladesh, Indonesia, Japan, India, Malaysia, Philippines, Sri Lanka, Thailand and Vietnam). As of 1999, WSD has been officially confirmed in at least nine countries in the Americas (Columbia, Ecuador, Guatemala, Honduras, Mexico, Nicaragua, Panama, Peru and the United States), and most recently (2005), it has hit Brazil. The major mode of transfer is through the movement of infected live animals (postlarvae and broodstock). A second important shrimp disease, Taura syndrome (TS), caused by the Taura syndrome virus (TSV) was previously reported only from the Western Hemisphere. However, TSV is now becoming widespread in Asia, most recently reported from Indonesia in 2002.

3. Transboundary aquatic animal diseases/pathogens

Aquaculture is faced with what is known as transboundary aquatic animal pathogens/diseases (TAAPs/TAADs), which are similar to the transboundary animal diseases or TADs in the livestock sector (Baldock, 2002; Bondad-Reantaso, 2004a). TAADs are diseases that are highly contagious or transmissible, having the potential for very rapid spread irrespective of national borders and causing serious socio-economic and possibly health consequences. The Office International des Epizooties (OIE) currently lists 35 pathogens/diseases of finfish, molluscs and crustaceans that fit three major criteria in terms of consequence, spread and diagnosis. Criteria for urgent notification for the listed aquatic animal diseases are:

- first occurrence or re-occurrence of a disease in a country or zone of a country if the country or zone was previously considered to be free of that particular disease;
- or occurrence in a new host species;
- or new pathogen strain or new disease manifestation;
- or potential for international spread of the disease;
- or zoonotic potential.

For non-listed diseases, the criteria for urgent notification is if there are findings in an emergency disease/pathogenic agent that are of epidemiological significance to other countries (OIE, 2003b).

Of the 35 listed diseases, 16 are diseases of finfish (one parasite species, *Gyrodactylus salaris*), 11 are diseases of molluscs (all but one are parasite species, e.g. *B. ostreae*, *H. nelsoni*, *Marteilia refringens*, *Mikrocytos mackini*, *P. marinus*) and 8 are diseases of crustaceans (none is of parasite origin). The Quarterly Aquatic Animal Disease Reporting System (QAAD) in the Asia-Pacific, jointly developed by the Network of Aquaculture Centres in Asia-Pacific (NACA), the Food and Agriculture Organization of the United

Nations (FAO) and OIE, currently lists 32 diseases, including many of the OIE-listed diseases (NACA/FAO, 2005). Among these are 14 diseases of finfish (11 OIE-listed); 6 diseases of molluscs (5 OIE-listed); 9 diseases of crustaceans (8 OIE-listed); there are diseases that are under the category of unknown diseases of a serious nature (1 disease of finfish; 2 diseases of molluscs). The current OIE list of diseases tends to focus on known, significant diseases and agents and covers the most commonly traded species such as salmonids, catfish, oysters and shrimps. The regional Asian list includes those diseases that are important to the region.

4. Impact of transboundary diseases in aquaculture

Infectious diseases are constraining the development and sustainability of the aquaculture sector through direct production losses and increased operating costs and indirectly, through restrictions on trade and impacts on biodiversity. Inadequate or poorly implemented biosecurity measures have led to significant losses due to aquatic animal diseases in many countries around the world.

Arthur and Subasinghe (2002) summarized the impacts of aquatic animal diseases on wild populations and biodiversity that can be measured in terms of:

- impact on aquatic community structure through changes in predator and prey populations;
- changes in host abundance (e.g. through altered genetic demands, altered host behaviour, increased mortality, decreased fecundity, increased susceptibility to predation);
- reduction of intra-specific genetic variation;
- local extirpation of susceptible components of aquatic communities;
- the possible extinctions of species.

The impacts of disease have been estimated in socio-economic terms (e.g. losses in production, income, employment, market access or market share, investment and consumer confidence; food shortages; industry failure or closure of business or industry). Analysis of economic impacts of aquatic animal diseases is very much a grey area in the literature. However, due to the frequency of occurrence and the magnitude of spread and effects, many countries are now providing some estimates of disease impacts. Tables 1–3 summarize some information on examples of socio-economic and other impacts of diseases in shrimp (Table 1), finfish (Table 2) and molluscan (Table 3) aquaculture. Losses are expressed as monetary estimates (in many cases a scale of millions of US$), percentage decrease in production, export losses, unemployment, closure of aquaculture operations and lost consumer confidence.

At the regional level, ADB/NACA (1991) reported that the minimum conservatively estimated lost farm production in 1990 to fish diseases (such as epizootic ulcerative syndrome (EUS) of fresh and brackishwater fishes, penaeid shrimp diseases and a variety of other diseases causing losses in freshwater finfish pond culture and marine cage culture) in 15 developing Asian countries was US$ 1.36 million (M). At the global level, combined estimated losses in production value due to shrimp diseases from 11 countries for the period 1987–1994 (i.e., Taiwan, Province of China—1987, Philippines—1989, Indonesia—1991, China—1992, Ecuador—1992, USA—1993, Bangladesh—1994, India—1994, Mexico—1994, Thailand—1994 and Vietnam—1994) were on the order of US$ 3019 M (Israngkura and Sae-Hae, 2002). At the national level, for example, the emergence of infectious salmon anaemia (ISA) cost the Scottish farming industry £20 M in the 1998/1999 outbreak and resulted in a continued annual cost to the Norwegian and Canadian industries of US$ 11 M and US$ 14 M, respectively (Hastings et al., 1999).

5. Economic investments and opportunities in aquatic animal health

Economic impacts have also been expressed in terms of costs of investment in disease research and control and health management programmes. Tables 4 and 5 provide some examples of information on some of the current economic investments in aquatic animal health in terms of developing and implementing ‘‘national strategies’’, setting up research institutes on aquatic animal health, operating reference laboratories, funding research and disease control programming, and investing in development programmes on

Table 1
Examples of socio-economic and other impacts of diseases in shrimp aquaculture in selected Asian and Latin American countries (from Bondad-Reantaso, 2004a)

Country	Disease/pathogen	Losses and other impacts	Reference
1992			
Thailand	Yellowhead disease (YHD)	US$ 30.6 M in 1992	Nash et al. (1995)
1993			
China PR	Shrimp diseases	US$ 420 M in 1993 60% Decline in production from 210,000 to 87,000 tonnes in 1993	Wei (2002) Yulin (2001)
Vietnam	Shrimp diseases Monodon baculovirus (MBV), white spot disease (WSD) and YHD	US$ 100 M in 1993	Khoa et al. (2001)
1994–1998			
Australia	Shrimp diseases: mid-crop mortality syndrome (MCMS), gill-associated virus (GAV)	US$ 32.5 M lost value of *Penaeus monodon* production during the period 1994–1998	Walker (2001)
Thailand	YHD and WSD	US$ 650 M in 1994; 12% production decline from 250,000 tonnes in 1994 to 220,000 tonnes in 1995; shrimp losses for 1997 reached nearly 50% of total farm output value. (Excludes losses in related businesses such as feed production, processing and exporting, ancillary services and lost income for labourers)	Chanratchakool et al. (2001)
Honduras	Taura syndrome virus (TSV)	Production decline by 18, 31 and 25% in 1994, 1995 and 1996, respectively.	Corrales et al. (2001)
India	YHD, WSD	Production loss of 10,000–12,000 tonnes during 1994–1995 caused by two viral epizootics (YHD); US$ 17.6 M economic loss in 1994 alone (WSD)	Mohan and Basavarajappa (2001)
Malaysia	WSD	Annual losses since 1995 estimated at US$ 25 M	Yang et al. (2001)
Bangladesh	WSD	US$ 10 M production losses in 1996; export losses; massive unemployment	Rahman (2001)
Panama	TSV	1996 Outbreak resulted to 30% reduction in production	Morales et al. (2001)
Costa Rica	TSV	TSV outbreak in 1996 caused reduction in survival rate from 65 to 15%.	Vargas (2001)
Philippines	Shrimp diseases (viral and bacterial)	Decline in export from 30,462 to 10,000 tonnes in 1997; great reduction in number of hatcheries	Albaladejo (2001)
Sri Lanka	WSD and YHD	Production loss of 1 B Rs. in foreign income during 1996 outbreak; 90% of production units closed (WSD); 68 and 70% drop in shrimp exports in terms of quantity and value in 1998 (mixed infection-WSD and YHD)	Siriwardena (2001)
1999			
Ecuador	WSD	US$ 280.5 M in 1999 equivalent to 63,000 tonnes; closing of hatchery operations; 13% laying off of labour force (26,000 people); 68% reduction in sales and production of feed mills and packing plants	Alday de Graindorge and Griffith (2001)
Honduras	WSD	13% Reduction in labour force	Corrales (2001)
Nicaragua	WSD	5–10% Survival rate	Drazba (2001)
Panama	WSD	US$ 40 M worth of export loss; closure of major hatcheries; loss of jobs (5000 people directly and indirectly involved in the industry)	Morales et al. (2001)

Table 2
Examples of socio-economic and other impacts of diseases in finfish aquaculture in selected Asian countries (updated from Bondad-Reantaso, 2004a)

Country	Disease/pathogen	Losses and other impacts	Reference
1932			
Indonesia	White spot disease (*Ichthyophthirius*) in Java barb, kissing gourami, common carp and giant gourami)	10,000 Dutch guilders, an amount that exceeded losses of salmonids in European countries caused by similar outbreaks between 1919–1928	Buschkiel (1935), Sachlan (1952)
1983			
Indonesia	*Lernaea cyprinacea* infection among common carp, Java barb, kissing gourami and giant gourami	30% Of hatchery production in main hatchery centers of Java, northern Sumatra and northern Sulawesi affected. In Java, an estimated 1.48 billion fry were lost, worth some 7.4 billion rupiahs (approximately US$ 11.4 M)	Djajadiredja et al. (1983)
1989–1993			
Malaysia	Diseases of cage-cultured grouper, snapper and seabass	US$ 1.3 M in potential income—combined loss estimates of private sector and government farms	Wong and Leong (1987)
Thailand	*Seabass diseases*	US$ 0.8 M in 1989	ADB/NACA (1991)
Thailand	*Grouper diseases*	US$ 1.07 M in 1989	ADB/NACA (1991)
China	Bacterial diseases of fish (*Aeromonas hydrophila*, *Yersinia ruckeri* and *Vibrio fluvialis*)	>US$ 120 M annual losses between 1990–1992	Wei (2002)
Thailand	Jaundice disease in catfish	US$ 4.3–21.3 M in 1992	Chinabut (2002a)
Malaysia	Vibriosis	US$ 7.4 M—outbreak in 1990	Shariff (1995)
Singapore	Grouper diseases	S$ 360,500 in 1993	Chua et al. (1993)
1994–1998			
Japan	*Marine fish disease*	US$ 114.4 M	Arthur and Ogawa (1996)
1998–2002			
Thailand	*Alitropus typus*	US$ 234–468/cage culture of tilapia in 1998–1999	Chinabut (2002b)
Philippines	Grouper diseases	75% Reduction in household income; 19.4% increased debt	Somga et al. (2002)
Singapore	Grouper iridovirus	>50% Mortality among Malabar grouper	Chang (2001)
China	Viral nervous necrosis (VNN)	100% Mortality among 3 species of grouper	Zhang (2001)
Singapore		80–100% Mortality among fry and fingerlings	Chang (2001)
Indonesia		100% Mortality of larvae in national hatcheries in 1999–2000	Yuasa and Koersharyani (2001)
Indonesia	Suspected Koi herpes virus (KHV)	50 Billion Rs. in one area alone during first 3 months of outbreak	NACA (2002), Bondad-Reantaso (2004c), FHS/AFS (2004)
		US$ 15 M	Sunarto et al. (2004)
Japan		US$ 1.4 M	Pro-Med, (November 2003), FHS/AFS (2004)

aquatic animal health. Table 6 provides information on investment opportunities (market and R&D investments) for aquatic animal health products (e.g. biologicals, antibiotics, antiparasitics, hygiene, nutraceuticals, etc.).

As previously mentioned, the socio-economic and other impacts of aquatic animal diseases are very much a grey area in the scientific literature. Although available data reveal high figures for both economic impacts (Tables 1 and 3) and investments (Tables 4

Table 3
Some examples of economic impacts of diseases on representative molluscan species (from Bondad-Reantaso and Berthe, in press)

Species	Pathogen/disease	Country/year	Impacts (losses, mortality rates, etc.)	Reference
Eastern oyster (*Crassostrea virginica*)	*Haplosporidium nelsoni* (MSX)	Chesapeake Bay, USA, since 1959	>90% Of oysters grown in the Bay	Andrews (1968)
	Haplosporidium nelsoni (MSX)	Canada, 2002	80% Mortalities	OIE Report (October 2002)
Japanese pearl oyster (Akoya oyster) (*Pinctada fucata martensii*)	Mass mortalities associated with a viral disease	Japan, since 1994	1996–1997—Annual mortality in all of western regions >400 M oysters equivalent to 50% of oyster production in Japan. Total economic loss: >30,000 million Japanese yen (mortalities and decreased quality of pearls produced)	Miyazaki et al. (1999)
			Responsible for black-lip oyster mortalities in Polynesia?	Jones (2002)
Manila clam *Ruditapes philippinarum*	*Perkinsus* sp.	West and south coast of Korea since 1997	Dramatic decrease in clam landings since 1993; clam landings in 1997 were 14,000 tonnes, 1/5 of the total landings in 1990	Park and Choi (2001)
Rock oyster (*Saccostrea glomerulata* (=*commercialis*)	*Marteilia sydneyi* (marteiliosis or QX disease)	Australia	>90% Prevalence single most important pathogen of rock oyster US$ 30 million worth of production in NSW Australia	Adlard and Weshe (2002), Kleeman and Adlard (2000)
Pacific oyster (*C. gigas*)	Herpes type virus disease		80–90% Mortalities of larvae and spat in hatchery and natural beds	Berthe (2002)
Pacific oyster (*C. gigas*)	*Marteilioides chungmuensis*	Japan	60% Prevalence during harvest period	Itoh et al. (2002)
Scallop (*Chlamys farreri*)	Possible virus-like etiology (Scallop acute viral necrotic disease)	North China, 1998	Mass mortality caused losses of US$ 0.18 B	Chong-ming Wang (pers. comm, 2002)
Abalone (*Haliotis diversicolor*)	Unidentified virus	North east coast of Taiwan Province of China, (similar epidemics with high mortalities occurred in southern China in 2003 (Drs. Choi and Dr Wang, pers. comm.)	400 Million TWD (US$ 11.5 M) loss to the domestic abalone industry. Annual product value of Taiwan abalone exceeds 7000 million TWD (US$ 200 M), including 2000 M TWD (US$58.8 M) from those raised in farms along the northeast coast. Dropped to 400 NTD from 600 NTD per kg.	Taipei Times (13 March 2003), Pro-Med (13 March 2003)
Black abalone (*H. cracherodii*)	Withering syndrome of abalone	California	Cumulative mortality over 99%	OIE (2003a,b)
Manila clam (*Ruditapes philippinarum*)	*Perkinsus* sp.	West and south coast of Korea since 1997	Dramatic decrease in clam landings since 1993; landings in 1997 were 14,000 tonnes, 1/5 of the total landings in 1990	Park and Choi, 2001

Table 4
Examples of economic investments in aquatic animal health programmes

Type of investment	Country/organization	Amount (US$ equivalent at current exchange rate)	Remarks
Aquatic Animal Health Strategy	Australia[a]: National Strategy on Aquatic Animal Health AQUAPLAN (1998–2003)	AUD 2.7 M (US$ 2.09 M)	Over four years to develop the plan
		AUD 3 M (US$ 2.32 M)	Over four years to implement a large portion of the plan
	United[b] States of America: National Aquatic Animal Health Task Force	US$ 375,000/year	Development of national plan
	Norway[c]: Ministry of Fisheries and Coastal Affairs	NOK 3.5–4 M (US$ 4.5–5.8 M)	Responsible for the ''Fish Disease Legislation'' (the part of the ''Food Act'' covering aquatic animals). Ministry gives funds for fish health work to, for example, National Veterinary Institute, Marine Laboratory, Institute of Fisheries Research.
	Norway[c]: Norwegian Food Safety Authority (NFSA)	NOK 60 M (US$ 77.1 M)	Has overall responsibility for the management of fish diseases in the field covered by the legislation (inspections, contingency plans, management restrictions, etc.). It also supports funding of surveillance and control programmes.
Research Institute or Reference Laboratory on Aquatic Animal Health	Thailand[d]: Aquatic Animal Research Institute (AAHRI), also an OIE Reference Laboratory for Epizootic Ulcerative Syndrome (EUS)	Thai Baht (THB) 55 M (US$ 1.426 M)	Includes renovation of old building (THB 10 M), purchase of new equipment (THB 20 M), operational cost for 5 years (THB 20 M) and management (THB 5 M) of AAHRI
	Norway[c]: OIE Reference Laboratory for Infectious Salmon Anemia (ISA)	NOK 200,000.00 (US$ 257, 138.00)	
	Norway[c]: OIE Reference Laboratory for *Gyrodactylus salaries*	NOK 50,000.00 (US$ 64, 291.00)	Excludes laboratory expenses, mostly inquiries
Research	China[e]	US$ 6 M	Research on diseases
	Thailand[d]	Thai Baht 20 M (US$ 5 M)	Research work at AAHRI and universities in the last few years
	Norway[c]	NOK 39 M (US$ 50.1 M)	Total for aquatic animal health research from Norwegian Research Council (2005) provided to various institutes such as National Veterinary Institute (NVI), Marine Laboratory
Disease control programmes	USA[f]	US$ 8.3 M	To combat infectious salmon anemia (ISA) (2002)
		US$ 11.7 M	To combat spring viremia of carp (SVC) (2003–2004)
	Canada[g]	US$ 34 M	Reactive disease control
	China[d]	US$ 73 M	Disease control

Table 4 (*Continued*)

Type of investment	Country/organization	Amount (US$ equivalent at current exchange rate)	Remarks
	Norway[c]	NOK 3.1 M (US$ 3.98 M)	funds received from National Food Safety Authority for implementation of surveillance and control program by the National Veterinary Institute (NVI)

[a] *Source*: Dr. Eva-Maria Bernoth, Australia.
[b] *Source*: Mr. Kevin Amos, USA.
[c] *Source*: Prof. Tore Hastein, Norway.
[d] *Source*: Dr. Supranee Chinabut, Thailand.
[e] *Source*: Dr. Wang, China.
[f] *Source*: Dr. Jill Roland, USA.
[g] *Source*: Dr. Sharon McGladdery, Canada.

Table 5
Examples of investments in programmes (development programmes from regional and national levels) and fish health services (private sector)

Organization	Funding allocation	Project details (project title, duration, number of participating governments etc.)
Food[a] and Agriculture Organization of the United Nations (FAO)	US$ 345,000.00	FAO/TCP/RAS 6714 (A) and 9605 "Ässistance for the Responsible Movement of Live Aquatic Animals"; 1997 to 2000, Regional programme, 21 governments in Asia-Pacific, Implemented by NACA
	US$ 395,000.00	FAO/TCP/RLA/0071 (A) "Assistance to health management of shrimp culture in Latin America"; Regional programme, 14 governments in Latin America
	US$ 364,000.00	FAO TCP/INS/2905 (A) "Health management in freshwater aquaculture"; 2002–2003, National programme, Indonesia
Asian[b] Development Bank (ABD)	US$ 290,000.00	RETA 5358, Fish Health Management in Asia-Pacific, Implemented by NACA
European[c] Union (EU)	€996,553 (approximately US$ 1.3 M)	ICA4-CT-2001–10028; "Hazard Analysis of antimicrobial resistance associated with Asian aquaculture environments" 2002–2005, three countries in SEA and three countries in EU
Asia-Pacific[d] Economic Cooperation (APEC)	US$ 116,000.00	APEC FWG 01/2002 "Capacity and Awareness Building on Import Risk Analysis for Aquatic Animals", excludes contribution from other partner organizations such as FAO, OIE and private sector; participated by 17 APEC economies and FAO and NACA member governments in Asia-Pacific and Latin American regions; 2000–2004; Implemented by NACA
Private[e] Sector (Norway)	NOK 25–30 M (approximately US$ 3.9–4.7 M)	Fish health service from private sector in Norway

[a] *Source*: Dr. Rohana Subasinghe, FAO.
[b] *Source*: Mr. Pedro Bueno, NACA.
[c] *Source*: Dr. Supranee Chinabut, AAHRI.
[d] *Source*: Dr. Melba Reantaso, FAO.
[e] *Source*: Prof. Tore Hastein, Norway.

Table 6
Estimated aquatic animal health market and R&D investment in 2004[a]

Segment	World			Asia		
	Market size (US$ M)	(%)	R&D investment (US$ M)	Market size (US$ M)	(%)	R&D investment[b] (US$ M)
Biologicals	68.6	7	10.3	19.2[c]	3	2.9
Antibiotics	274.4	28	8.2	192.0	30	5.8
Antiparasitics	29.4	3	2.1	19.2	3	1.3
Hygiene	137.2	14	6.9	153.6	24	7.7
Nutraceuticals	431.2	44	21.6	230.4	36	11.5
Others	39.2	4	1.2	25.6	4	0.8
Total	980.0	100	50.2	640.0	100	30.0

[a] *Source*: Stirling Aquaculture (1998), Bostock (2002), various personal correspondences.
[b] For commercial companies; excluding university and institute research funded by government.
[c] Mainly in Japan.

and 6), so far no systematic economic assessment has been carried out. In the foreseeable future, there will be increasing demand for such assessments in order to gain attention and continuous support from both the public and private sectors.

6. Strategies for combating diseases in Asian aquaculture

Most of the strategies listed below have been previously highlighted in a number of publications (e.g. Bondad-Reantaso et al., 2001a,b; Subasinghe et al., 2001; Bondad-Reantaso, 2004b; Bondad-Reantaso and Subasinghe, in press). These are general strategies currently being implemented in the Asia-Pacific region (but having applicability to other regions of the world), and apply to all infectious diseases.

6.1. International codes

In order to minimize the risks of pathogens/diseases associated with aquatic animal movements, there are a number of existing global instruments, agreements, codes of practice and guidelines (either voluntary or obligatory) that, if implemented, provide certain levels of protection. These include:

- OIE's *Aquatic Animal Health Code* (OIE, 2003a);
- the *Code of Practice on the Introductions and Transfers of Marine Organisms* (ICES, 1995) of the International Council for the Exploration of the Seas (ICES);
- the *Codes of Practice and Manual of Procedures for Consideration of Introductions and Transfers of Marine and Freshwater Organisms* (Turner, 1988) of the European Inland Fisheries Advisory Commission (EIFAC).

There are also relevant articles included in the *Code of Conduct for Responsible Fisheries* (CCRF) of the Food and Agriculture Organization of the United Nations (FAO) (FAO, 1995), the Convention on Biological Diversity (CBD, 1992) and the Sanitary and Phyto-sanitary (SPS) Agreement (Chilaud, 1996) of the World Trade Organization (WTO). Countries are trying their best to fulfill their responsibilities to implement the provisions of these international codes despite limited capacities and resources. It is essential to assist governments, particularly those of developing countries, in improving their ability to comply with these international obligations.

6.2. Regional guidelines

Because many countries in the Asian region share common social, economic, industrial, environmental, biological and geographical characteristics, a regionally adopted health management programme is considered a practical approach. Some of the provisions in the current international protocols are not always practically applicable to the diseases of concern to the Asian region. Therefore, it was deemed important to focus on the species and diseases affecting those species. The *Asia Regional Technical Guidelines on Health Management for the Responsible Movement of Live Aquatic Animals and the Beijing Consensus and Implementation Strategy* (or the "Technical Guidelines") (FAO/NACA, 2000, 2001) was based on a set of guiding principles developed through a regional project of FAO and implemented by the Network of Aquaculture Centres in Asia-Pacific (NACA) using a consultative process that involved representatives from 21 participating governments and technical assistance from regional and international experts on aquatic animal health. The Technical Guidelines describe a number of health management considerations aimed at minimizing the risk of disease spread via aquatic animal movements and were developed to:

- assist countries in the Asia-Pacific to move live aquatic animals in a way that minimizes the disease risks associated with pathogen transfer and disease spread, both within and across boundaries;
- enhance protection of the aquatic environment and biodiversity, as well as the interests of aquaculture and capture fisheries;
- provide a mechanism to facilitate trade in live aquatic species and avoid unjustifiable trade barriers based on aquatic animal health issues;
- implement relevant provisions of FAO's CCRF and other international treaties and agreements (e.g. WTO's SPS agreement) applicable to the Asian region.

The development of the Technical Guidelines took into account the different socio-economic and environmental circumstances of the participating countries in the Asia-Pacific region, the diversity of infrastructures (in terms of expertise and institutional capability), the wide range of aquatic species being moved, the different reasons for such movements and the diversity of pathogens currently known.

6.3. National strategies on aquatic animal health management

National strategies contain the action plans of government at the short, medium and long-term, following the concept of "phased implementation based on national needs" for the implementation of the Asia Regional Technical Guidelines (FAO/NACA, 2001). The National Strategy framework includes elements such as national coordination, legislation and policy, list of pathogens, institutional resources, diagnostics, health certification and quarantine, surveillance and reporting, disease zoning, contingency planning, import risk analysis, capacity building, awareness building and communication, farmer/private sector involvement, financial resources, monitoring and evaluation and regional cooperation. The various processes and examples of national strategies are provided by Bondad-Reantaso (2004b); one specific example is Australia's AQUAPLAN (AFFA, 1999). Asian governments have agreed to implement the Technical Guidelines at the national level through the National Strategy framework.

6.4. Diagnostics, therapy and information technology

Because of the scale of resource expertise and infrastructure required (e.g. training, facilities, resources) for disease diagnostics, FAO/NACA (2000) recommended the use of three levels of diagnostics:

(a) *Level* I: field observation of the animal and the environment, clinical examination;
(b) *Level* II: laboratory observations using parasitology, bacteriology, mycology and histopathology;
(c) *Level* III: laboratory observations using virology, electron microscopy, molecular biology and immunology.

The three levels have broad-scale application to disease detection and diagnostics. Therefore, countries are encouraged to move from one level to the next as capacities are improved and as resources become available (Bondad-Reantaso et al., 2001a,b).

The application of molecular-based technologies (Level III) in aquaculture health has advanced rapidly (e.g. the use of polymerase chain reaction (PCR) in shrimp and molluscan disease diagnostics). Walker and Subasinghe (2000) reported the findings of an expert consultation on "Research needs for the standardization and validation of the detection of aquatic animal pathogens and diseases" that recognized that these tools provide quick results, with high sensitivity and specificity, and are particularly valuable for infections that are difficult to detect using standard histology and tissue-culture techniques. However, they have limitations in terms of appropriate applications, standardized sampling, testing procedures and interpretation of results and are also of limited value to newly emerging diseases where the causative agent is unknown. In such cases, histology, a non-specific general technique focusing on the potential causative agent/s, is still the most appropriate method to interpret pathology accurately. Even as the further development of these technologies leads to enhanced rapid detection and diagnosis of disease crucial for early and effective disease control, there will be practical problems in their application. Subasinghe et al. (2001) recommended that development of standardized methods for disease diagnosis and screening of pathogens, along with regular evaluation of their effectiveness as compared with other diagnostic methods should be a priority task.

Vaccination is another established, proven and cost-effective method for controlling certain infectious diseases in cultured animals. Vaccines reduce the severity of disease losses, reduce the need for antibiotic use, leave no residues in the product and do not induce pathogen resistance. There are currently many commercially available vaccines for finfish diseases, and a few more are under development (see Subasinghe et al., 2001). In Japan, for example, the use of injection vaccines is now widespread among maricultured animals, proved effective against bacterial (e.g. *Lactococcus garvieae* infection of yellowtail) and viral infections (e.g. iridoviral infection of red sea bream) and has changed the patterns of disease occurrences. In conjunction with good health management and good husbandry practices, there is great potential for the use of vaccine technology for specific use in Asian aquaculture (Grisez and Tan, 2005).

6.5. Biosecurity

There will be increasing demand for improved aquatic animal biosecurity. This will be driven by multiple objectives such as resource protection (aquaculture, wild fisheries and the general environment), food security, trade, consumer preference for high quality and safe products, production profitability, investment and development issues, and new threats of emerging health problems (e.g. new diseases/pathogens, new hosts for well-studied pathogens). Biosecurity programmes have a strong scientific basis and use risk assessment to evaluate the most significant disease hazards, their possible routes of entry, the likelihood of them becoming established, the possibilities of spread and risk management approaches in order to ensure appropriate protection. Risk analysis for aquatic animal trade provides a science-based, justifiable means to estimate the risks posed to aquaculture and aquatic biodiversity due to pathogen introduction or, in a more specific form, the risk to a particular farm unit. Such analysis makes use of scientific and technical information as a basis for policy development and decisions, and can also be used to identify knowledge gaps and thereby assist in prioritizing future research direction and priorities. The process employs sound epidemiological principles, approach and data. Epidemiology, the study of the frequency, determinants and distribution of disease, has as its ultimate objective the resolving of animal health problems (Thursfield, 1995). Epidemiological studies generate the data required for risk analyses; biosecurity measures require good information for accurate assessment, which leads to appropriate risk management decisions. Thus, biosecurity, risk analysis and epidemiology are highly interrelated and are all aimed at making good use of scientific research for disease prevention, control and management.

Epidemiology for aquatic animal health is a new concept introduced into the region in 1996 (Bondad-Reantaso and Subasinghe, in press), but is now being applied and integrated in various disease investigations and diagnostics (Lilley et al., 2002; Corsin et al., 2001; Morgan, 2001; Mohan et al., 2002). Most recently, epidemiology was one of the key approaches used in the emergency investigation of a serious disease outbreak of koi and common carps in Indonesia. There will be more demand for aquatic animal epidemiologists in the region, and the use of epidemiology will significantly improve health management, risk analysis and disease control.

Of equal importance is the need for fundamental information that characterizes diseases in aquaculture. Import risk assessment would of necessity set the risk as “high” if there are little data on modes of transmission, host susceptibility, tolerance to abiotic factors (e.g. temperature, salinity), or immune response elicited for a particular pathogen under consideration. Furthermore, the need for clear and unambiguous identification of potential pathogens using morphological and molecular diagnostic tools is paramount prior to making decisions on the disease status of any aquaculture zone. This risk is emphasized by the accelerated discovery of cryptic species based on variable DNA motifs.

Efforts to build capacity and raise awareness on the concepts underlying risk analysis (RA) and its application to aquatic animal movement are increasing (Rodgers, 2001; Arthur and Bondad-Reantaso, 2004). References on RA for aquatic animals are limited but growing (AQIS, 1999a,b; OIE, 2003a; Arthur et al., 2004; Arthur and Bondad-Reantaso, 2004). Countries will be confronted with a range of conditions and scenarios when conducting a RA, and regulations will vary from country to country. For developing countries, the greatest struggle will be for information (both quantity and quality), capacity of staff, disease surveillance to demonstrate country/regional freedom from specific disease agents, legislation and decisions for determining what constitutes ‘‘acceptable risks’’ (Arthur et al., 2004; Bondad-Reantaso and Subasinghe, in press). As more skills and expertise on risk analysis are developed and as more scientific information becomes available, we can expect practical models to be developed that will provide useful guidance to countries. In addition, there are always expert input and experiences and important lessons from the livestock and plant sectors that can be utilized.

6.6. Surveillance and reporting

The disease situation in aquaculture is changing rapidly in an unpredictable way due to the current period of rapid change in the international trading environment—affected by globalization, increasing aquaculture production and microbial adaptation (Subasinghe et al., 2004). Thus, in this age of uncertainty due to food insecurity and bioterrorism, the use and application of ‘‘surveillance’’ and ‘‘reporting’’ has become very timely. The Asia-Pacific region is unique in that a quarterly aquatic animal disease reporting system has been established since mid-1998 by NACA and FAO in cooperation with OIE (NACA/FAO, 1999). This is an important step towards building the essential information for instituting control and eradication measures, as well as to support early warning, risk assessment, contingency plans and emergency preparedness programmes for aquatic animal diseases and epizootics.

The application of disease surveillance and reporting to aquatic animal health and aquaculture is complicated by factors such as the wide ranges of socio-economic and technological development in many countries, the diversity of species cultured, the range and complexity of environments, the nature of containment, the intensity of practice, and the variety of culture systems and types of management (Reantaso et al., 2000). Although there are still problems with respect to accuracy, consistency and timely submission of reports, the system is evolving and reporting governments are starting to realize the benefits of such a system. Activities and further work are continuing towards providing assistance to regional disease surveillance, reporting and capacity building to improve the quality of the reports, and enhance effective surveillance and accurate analysis of disease reports. Two most recent publications that are useful when developing surveillance programmes for aquatic animal diseases are those of Cameron (2002) and Subasinghe et al. (2004).

Countries will be faced with significant challenges with respect to implementing surveillance and disease zoning programmes, since these require costly investments. It is therefore essential to weigh the economic benefits of such programmes against the country’s aquaculture potential. Some of the challenges include establishing programmes that are practical, cost-effective and capable of implementation within the constraints of existing disease detection techniques, resource availability and technical capacity. There will be more need for epidemiologists and the application of epidemiology in analysing disease situations. If political will and commitment from responsible authorities and cooperation at all levels can be achieved, surveillance and zoning have great potential to effectively minimize the spread of aquatic animal diseases and enhance trade.

6.7. Research

With the increasing use of risk analysis for disease prevention and the development of precautionary management measures, generating information to support biosecurity assessments should be given high priority. Research to support aquaculture biosecurity should focus, for example, on the pathways of pathogen spread, methods for inactivation of infectivity, and ‘‘barrier’’ vaccination strategies. Epidemiological research should include investigation of biological factors (identification of at-risk populations, hazards, pathways, pattern of spread, incubation period, nature of the pathogen); risk factors; interventions; methodologies (e.g., surveillance techniques, disease outbreak modelling, use of geographic information systems). Risk analysis information/knowledge requirements should be given high priority. Essential research areas, for example, include pathogen studies, information on trade and most importantly, biological pathways for the introduction (release assessment), establishment (exposure assessment) and spread (consequence assessment) of a pathogen. Other important areas of research include studies on host susceptibility; modes of transmission; infectivity, virulence and stability; intermediate hosts and vectors; effects of processing, storage and transport. For newly emerging diseases as well as some diseases in poorly studied aquatic animal species, basic studies on their pathology and methods for rapid and accurate diagnosis (including standardization, validation and inter-calibration) are essential to facilitate accurate risk assessment and biosecurity management. Increased surveillance of wild fish to detect significant disease problems at an early stage will also be required.

6.8. Institutional strengthening and manpower development (education, training and extension, diagnostic services)

Subasinghe et al. (2001) indicated that although there has been an increase in the number of diagnostic laboratories, universities and other institutions offering short and long-term training courses in fish and shellfish health, the increase in number has not matched the needs of the rapidly developing aquaculture sector, especially in the developing regions of the world, where most aquaculture activities take place. Because of the wide range of resource expertise and infrastructure required for disease diagnostics, FAO/NACA (2000) recommends the promotion of three levels of diagnostics (Levels I, II and III) according to existing resources (see Section 6.4).

Reference laboratories and collaborating centers of expertise are essential to the successful implementation of any aquatic animal health programme because they:

(a) provide a range of services and assistance such as generalized support services and confirmatory diagnosis of both current and newly emerging diseases;
(b) facilitate research and act as contact centers for advice and training;
(c) are crucial partners in standardizing, validating and assisting in the quality control of development and research programmes.

There are a number of OIE Reference Laboratories in the Asia-Pacific region (located in Australia, Japan and Thailand) dealing with specific disease problems. In addition to these disease centers, in 2001, NACA established a Regional Advisory Group on Aquatic Animal Health (AG), which is an official group of experts that is institutionalized and financed by the national governments, under NACA’s inter-governmental framework. The AG meets annually to provide high level technical advice to NACA for better health management in the region. Through the AG and its activities, formal technical assistance and advice are now provided by FAO, NACA and OIE to Asian governments. NACA also recently launched a ‘‘regional resource base’’ initiative that comprises three levels: regional resource experts (RRE), regional resource centres (RRC) and regional reference laboratories (RRL). A networking of these three levels of people and institutions will maximize provision of diagnostic support and assist in building capacity for effective implementation of aquatic animal health management strategies. The first step in the process is soliciting members of the RREs who will support the following activities:

- answering technical questions related to their field of expertise;
- assisting in development of disease cards, diagnostic manuals and supporting documents;
- providing diagnostic assistance, as far as possible, during disease emergencies.

6.9. Emergency response to disease epizootics

The Asia-Pacific region has been plagued with many disease emergencies during the last three decades. The most significant disease emergencies include that of EUS, shrimp viral diseases (WSD, YHD, IHHN, etc.), Akoya pearl oyster mortalities, and most recently, KHV and abalone mortalities. In a way, the region has learned to deal with the emergency situation using available limited resources, expertise and facilities. Some of the important lessons and valuable insights learned from dealing with those epizootics include the need for:

- regional and international cooperation;
- increased awareness on emerging diseases in other parts of the globe and the possibility of their spread to the Asian region;
- improved diagnostic capabilities at both the national and regional levels;
- pro-active reporting of serious disease outbreaks as a mechanism for early warning;
- contingency plans at both the national and regional levels;
- improved compliance and implementation of policies reached at the regional and international levels;
- emergency preparedness as a core function of government services;
- advanced financial planning such that adequate funds can be immediately provided to address serious emergency disease situations at both the national and regional levels.

In 2004, the FAO sponsored a regional workshop on ‘‘Emergency Preparedness and Response to Aquatic Animal Diseases in Asia’’ that reviewed regional experiences in responding to disease emergencies as a basis for identifying actions to reduce impacts of disease epizootics, as well as strengthening preparedness and response to future disease emergencies. This workshop has again provided a window of opportunity for increasing regional capacity to deal with health problems affecting aquaculture.

7. Opportunities for fisheries biologists and veterinarians

Aquatic animal health management has only recently assumed high priority in many aquaculture-producing regions of the world. This was stimulated by the serious socio-economic losses, environmental impacts and investment costs involved, as previously discussed in this paper. Many countries have improved their laboratory facilities, diagnostic expertise, and control and therapeutic strategies in order to handle disease outbreaks more effectively. There has also been some progress in dealing with aquatic animal disease problems in terms of increasing awareness, creating effective policy and legislation, and enhanced research and manpower development. However, this progress has not matched that of the rapidly developing aquaculture sector.

The Quarterly Aquatic Animal Disease Reporting System for Aquatic Animal Diseases in Asia-Pacific is a good example of a mechanism that has paved the way for establishing functioning linkages between fisheries and veterinary authorities. There is more room for inter-disciplinary studies to expand this window of opportunity for fisheries biologists and veterinarians to work together in research, diagnostics, extension and training. Taxonomy, although a significant branch of science is currently less well funded by various research agencies worldwide. However, it remains of critical importance for the first and all important accurate identification of pathogens in aquatic animal health, and will continue to be an important field and its value will be highlighted in risk analysis studies. Epidemiology will continue to be sought after as one effective approach to disease investigation and control. In the foreseeable future, we can expect to see more involvement of veterinarians in dealing with diseases affecting aquatic animals.

8. Conclusions

Addressing health questions with both pro-active and reactive programmes has become a primary requirement for sustaining aquaculture production and product trade. The current strategy in the Asia-Pacific region emphasizes responsible health management to minimize the risks of disease incursions brought about by the movement of live aquatic animals and their products. The regional Technical Guidelines provide valuable guidance for national and regional efforts in reducing these risks and a strong platform for mutual cooperation at the national, regional and international levels. There is strong support at various levels to implement the Technical Guidelines and National Strategies. The aquaculture sector will continue to intensify; trade in live aquatic animals will also persist because it is a necessity for aquaculture development at both the subsistence and commercial levels. The risk of major disease incursions and newly emerging diseases will keep on threatening the sector, and unless appropriate health management measures are maintained and effectively implemented, the government and private sectors will be faced with more costs in terms of production losses and the efforts needed to contain and eradicate diseases, funds that would have been better spent in preventing their entry into the system. Focussing efforts on prevention, on better management practices and on maintaining healthy fish maybe more important than focussing on why fish get sick. Health management is a shared responsibility, and each stakeholder's contribution is essential to the health management process.

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