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The spread of pathogens through trade in aquatic animals and their products

C.J. Rodgers (1), C.V. Mohan (2) & E.J. Peeler (3)

(1) Institut de Recerca i Tecnología Agroalimentáries (IRTA)-Sant Carles de la Ràpita, Crta. Poble Nou s/n, Apartat de Correus 200, 43540 Tarragona, Spain
(2) Network of Aquaculture Centres in Asia-Pacific, Suraswadi Building, Department of Fisheries, Kasetsart University Campus, Ladyao, Jatujak, Bangkok 10900, Thailand
(3) Centre for Environment, Fisheries and Aquaculture Science, Barrack Rd, Weymouth, DT4 8UB, United Kingdom

Summary

It is well known that the transboundary spread of infectious diseases is aided by trade in live animals and the consequences can be severe if, as a result, a pathogen broadens its host range to new species. Trade in aquatic animal species is increasing, and aquaculture is also expanding to meet the growing human population's demands for animal protein. Moreover, it is clear that aquaculture has created potential new pathways by which pathogens and diseases may be introduced or spread to new areas. The risk of pathogen transfer is generally considered greater for the movement of live aquatic animals than for the movement of processed and dead products. The currently available health standards support the concept of minimising the risk of disease and pathogen incursion while, at the same time, avoiding unjustifiable or unnecessary impediments to trade. Nevertheless, the international spread of diseases through the movement of animals still occurs, despite these standards. Consequently, this paper considers the evidence linking international trade in aquatic animals and aquatic animal-derived products with the transmission and spread of diseases. The authors provide examples of pathogen transfer leading to disease spread and consider the situation of emerging diseases, as well as the need for a holistic approach to deal with risk-based threats at their source.

Keywords

Aquatic animal – Aquatic animal disease – Health standards – International trade – Transboundary pathogen.

Introduction

The movement of infectious agents can occur through various processes, including host migration and anthropogenic movement of live animals (42, 45).

The increasing globalisation of aquaculture and the associated increase in trade has created new pathways by which pathogens may be spread to new areas (73). Intensive aquaculture tends to facilitate the emergence of pathogens (71, 74, 99), which may then spread through global trade (7, 83). The risk of pathogen transfer is greater for the movement of live aquatic animals than for the movement of dead products and has resulted in the spread of aquatic animal diseases to many countries (44). The sheer volume of international trade has greatly increased the likelihood of the intentional or unintentional movement of aquatic species and any pathogens they might harbour (38).

The growth of aquaculture in recent decades has been dependent on the international movement of aquatic animals and, in particular, the introduction of non-native species. For example, rainbow trout (*Oncorhynchus mykiss*) are farmed across the globe, Pacific oysters (*Crassostrea gigas*) dominate shellfish production in Europe and many species of shrimp (e.g. *Litopenaeus vannamei*) are farmed outside their original ranges. Irrespective of the disease

Table I
Some important aquatic animal transboundary diseases

Infectious agent (disease)	Host	Origin of infection	Area of establisment	Year	Species / commodity introduced	Impact
Bacteria						
Aerococcus viridans (gaffkaemia)	European lobster (*Homarus gammarus*)	North America	UK	1978	Live American lobsters (*H. americanus*) (2)	No observed impact on wild populations. Clinical disease observed in facilities holding wild-caught animals
Xenohaliotis californiensis	European abalone *Haliotis tuberculata*	North America	Spain	1988	Red abalone *H. rufescens* (6)	Mortality of juvenile abalone in Galicia, Spain
Yersina ruckeri (enteric red mouth)	Wide host range (salmonids and non-salmonids)	North America	Europe	1981	Live minnows (*Pimephales promelas*) imported from the United States to France for live bait (72)	Serious disease in rainbow trout production in Europe, causing a high level of morbidity and significant control costs
Viruses						
Infectious haematopoietic necrosis virus	Salmonids (e.g. *Salmo trutta*)	North America	Europe	1987	Rainbow trout (*Oncorhynchus mykiss*) eggs (11)	Mortality and morbidity in farmed rainbow trout. No impact observed in wild populations
Infectious myonecrosis virus	Penaeid shrimp	Brazil	Indonesia	2002	Imported *Penaeus vannamei* broodstock	Significant economic losses in Indonesia
Koi herpesvirus	Carp (*Cyprinus carpio*)	Israel	Worldwide	1996	Carp for the ornamental pet trade (43)	Mortality and morbidity in carp farms and fisheries
Pilchard herpesvirus	*Sardinops sagax*	Unknown	Australia	1995	Unpasteurised, fresh, frozen, wild-caught fish (53)	Epidemic in wild pilchard population, leading to huge reduction in biomass and long-term population reduction
Ranavirus (genus)	Amphibians, reptiles and fish	Unknown, probably North America	Worldwide	1990s	Imported amphibians (B. Hill, personal communication)	Common frog mortalities in the UK, but no evidence of population declines (16)
Salmonid alpha virus (sleeping disease)	Salmonids	France	UK	2001	Rainbow trout carcasses introduced to the UK (41)	Unknown
Taura syndrome virus	Penaeid shrimp	Latin America	Some countries in Asia (Thailand, Vietnam, Indonesia)	1992	Imported *P. vannamei* broodstock	Significant economic losses in culture systems
White spot syndrome virus	Wide host range (almost all aquatic crustaceans)	Asia	Worldwide	1992	Movement of live broodstock and seed	Endemic in all shrimp-farming countries, continues to cause significant economic losses in aquaculture systems
Fungi						
Aphanomyces astaci (crayfish plague)	European crayfish species (e.g. *Astacus fluviatilis*, *A. astacus*)	North America	Europe	1860s	Introduction probably mechanical (ballast water or fish vectors) (2); reintroduction via signal crayfish imports from North America in 1960s	High mortality of native European crayfish, habitat degradation, predation on fish eggs, etc.
Batrachochytrium dendrobatidis (chytridiomycosis)	Wide host range (>13 amphibian families)	Unknown (probably the Americas)	Worldwide	1990s	Potential routes of introduction to Europe include movement of amphibians for the pet trade; zoo animals; food trade (e.g. bullfrogs); laboratory animals (e.g. *Xenopus*) (18)	Localised mortality events in amphibian populations (31)

UK: United Kingdom

Table I (cont.)
Some important aquatic animal transboundary diseases

Infectious agent (disease)	Host	Origin of infection	Area of establis-ment	Year	Species / commodity introduced	Impact
Parasites						
Anguillicoloides crassus	European eel (*Anguilla anguilla*)	Japan	Germany	1980s	Asian eels (*A. japonicus*) (56)	High mortality rate in infected European eels, potential significant contribution to the decline of eel populations
Bonamia ostreae	*Ostrea edulis*	North America	France	1970s	*O. edulis* reintroduced from North America (15)	Decimation of native oysters (*O. edulis*) in Europe
Gyrodactylus salaris (gyrodactylosis)	Atlantic salmon	Sweden	Norway	1973	Baltic strains of Atlantic salmon (52)	Reduction of over 95% in wild Atlantic salmon populations in 45 affected rivers in Norway
Haplosporidium nelsoni	None – no recorded spread from the introduced host	Canada or Japan	France	1993	Pacific oysters (*Crassostrea gigas*) (86)	No observed impact, recorded at low prevalence
Myxobolus cerebralis (whirling disease)	Salmonids	Europe	North America	1960s	Introduced to North America with imports of live trout species and carcasses	Population declines in wild trout populations
Sphaerothecum destruens (rosette agent)	Cyprinids, salmonids	Unknown, probably Asia	UK	2005	Topmouth gudgeon *Pseudorasbora parva* (39)	High mortality of cyprinids, in particular, sunbleak *L. delineatus* and salmonids in the United States, including Chinook and Atlantic salmon

UK: United Kingdom

risks involved, aquaculture and global trade will continue to expand (73). Since some risk is inevitable with trade in live aquatic animals, health management procedures, policies and practices must operate to minimise the risk while, at the same time, avoiding the imposition of unnecessary obstacles to trade and aquaculture development (28).

The devastating effects of diseases such as epizootic ulcerative syndrome (EUS) in freshwater fish, *Gyrodactylus salaris* in Norwegian salmon, viral nervous necrosis in marine fish, viral haemorrhagic septicaemia (VHS) in marine and freshwater fish, white spot syndrome virus (WSSV) in penaeid shrimps, white tail disease in *Macrobrachium rosenbergii*, as well as the emerging infectious myonecrosis virus (IMNV) in *Litopenaeus vannamei* in Asia, demonstrate the vulnerability of aquaculture and wild populations to disease emergence. More recently, the widespread mass mortalities of koi and common carp (*Cyprinus carpio*) in Indonesia, Japan and, to a lesser extent, Europe, due to koi herpesvirus (KHV), have re-emphasised the impact that diseases can have on local economies and the sustainability of the aquaculture sector (43). Disease problems may arise quickly in any country's aquaculture sector, often with serious economic, social and ecological consequences, and they may be difficult or impossible to eliminate once established. This is especially true for open systems operating in rivers, lakes and coastal bays. The impact of emerging diseases has been especially severe when a pathogen has extended its range to species with little or no innate immunity (80).

This paper considers the evidence linking international trade in aquatic animals and their products with the transmission and spread of aquatic animal diseases. Some examples of pathogen transfer leading to disease spread are given for fish, molluscs, crustaceans and amphibians. The authors consider this issue in the light of current biosecurity concerns and the need for additional standards to reflect the growth and nature of trade in aquaculture-based commodities.

General concepts and pathways

Transboundary aquatic animal diseases are highly contagious, have the potential for very rapid spread, irrespective of national borders, and cause serious socio-economic consequences (5, 8, 45). Key examples are described in Table I. Translocation of aquatic animals is frequently identified as an event that has preceded major outbreaks of a disease that was previously unknown in the affected region or species (20). In addition, rapid spread is linked to naïve susceptible populations, as well as the lack of barriers to dispersal in the aquatic environment (e.g. open farming systems) and the potential for long-term survival of pathogens outside the host (69).

The main purpose of global aquaculture production is food supply, although there is significant production of aquatic animals for conservation and recreational fisheries, the pearl industry and for research, as well as for marketing as ornamental, particularly fish, species. The sector of ornamental aquatic organisms is, in fact, growing significantly and is currently receiving more attention for its potential role in pathogen transfer (102). Consequently, a pathogen could be introduced through any one of a number of different routes. These include live fish, contaminated water, eggs and fomites, which are all potential sources of introduction, although the likelihood of establishment and the impact of each introduction will vary, depending on the end use, as well as the disease situation at source. However, these routes require better characterisation to understand their potential for disease dissemination. Introduction also depends on the pathogen's characteristics and its interactions with aquatic animals or their products, as well as the influence of vectors of all types, contaminated water and contaminated wrappings or packaging.

International trade and disease spread

Trade overview

In recent decades, there has been rapid growth of international trade in aquatic animals. However, more than 90% of the 50 million tonnes (live weight equivalent of world fish production) that are internationally traded is dead product (26). Freezing is the main method of processing fish for food use (50% of the total processed), followed by prepared and preserved (29%), and cured fish (21%) (27). In addition, some unpasteurised products are also internationally traded for use as feed for aquatic animals, providing a possible pathway for pathogen transfer, and yet the safety of such aquatic fish meals for aquatic animals is not well understood or documented. The main aquatic animal commodities traded internationally are shown in Table II.

Despite the large volumes of trade, there is a paucity of scientific data on the role of these products in disease spread, particularly information on pathogen survival. This may be due to a historical lack of tracing capability for aquatic product in most countries. However, in general, the risk of pathogen transfer is greater with live aquatic animals than with dead products, the safety of which depends on the extent of processing.

Table II
Main aquatic animal commodities traded internationally

Commodity	Purpose	Main species
Live animals	Aquaculture	The development of aquaculture has relied on the translocation of non-native species. Some production systems depend on movement of juveniles from specialist producers (e.g. rainbow trout and Atlantic salmon). Oyster spat are moved across political boundaries for relaying
	Companion animal trade	Many species of amphibians, fish and some crustaceans are widely traded internationally
	Food	Molluscs and crustaceans are generally traded live for food
Eggs	Aquaculture	International trade in Atlantic salmon and rainbow trout eggs
Product	Human consumption	Range of products from fresh whole animals, frozen carcasses, canned, smoked, etc.
	Feed in aquaculture	Low-value, wild-caught marine fish are transported frozen (unpasteurised) and used as feed for farmed fish

Trading blocks are essentially zones designed to encourage free trade between members and they rely on agreements related to tariffs and standards. Using the European trading block as an example, Table III shows the aquatic animal products imported into the 27 European Union (EU) countries, as well as those traded within the EU in 2009 (23). In the case of fish, the figures show that approximately eight times more live fish were traded between EU Member States than were imported into the EU as a trading block, while the ratio of intra- and extra-trade for fish products was almost the same (1.2 times more intra-trade). A similar trend can be seen for bivalve molluscs, non-bivalve molluscs and crustaceans. This is important when considering the risk of transferring aquatic animal pathogens into a trading block. The controls already in place enable a trading block to have confidence in its internal health status, which provides assurances for safe movement of a high-risk group, such as live aquatic animals. This contrasts with imports from third countries that cannot always be assumed to be subject to the same surveillance standards. Nevertheless, the standards applied within the trading block must be robust and able to deal quickly with an emergency situation because disease spread within a block is likely to be rapid, due to the high volume of internal trade not subject to border inspection.

With respect to ornamental fish, over one billion fish, comprising more than 4,000 freshwater and 1,400 marine species, are traded internationally each year (102). Although reliable statistics on ornamentals are difficult to obtain, the volume of trade has increased considerably in

Table III
Live aquatic animals and their products imported into the 27 countries of the European Union and traded within the European Union in 2009 (23)

Category (HS classifications)	**Quantity (× 100 kg)**	
	EU-27 extra (a)	**EU-27 intra (b)**
Fish		
Live ornamental fish	39,797	105,824
Other live fish	13,158	339,021
Fresh, chilled fish or fish products	8,071,762	10,364,967
Frozen fish or fish products	6,558,726	7,099,838
Bivalve molluscs (oysters, scallops and mussels)		
Live, fresh or chilled (c)	53,582	1,718,897
Frozen, dried or salted products (d)	336,362	256,113
Non-bivalve molluscs (cuttlefish and octopus)		
Live, fresh or chilled	38,928	315,155
Frozen or cooked products	3,580,479	869,323
Crustaceans (shrimps and prawns)		
Live, dried or salted crustaceans	19,644	277,292
Frozen or cooked products	4,690,950	1,237,237

HS: Harmonised System (Customs trade classification codes)
a) Quantity imported from third countries
b) Quantity traded between European Union Member States
c) Includes frozen oysters
d) Excludes frozen oysters

recent years. Table III indicates that the EU trading block alone imported 39,797 × 100 kg of ornamental fish in 2009, compared with an internal trade of 105,824 × 100 kg (23).

Examples of disease spread through international trade

Fish

International trade in fish and shellfish has introduced previously unknown parasites into Japan (78), and Yoshimizu (114) showed the connection between disease outbreaks in salmonid fish and imports of salmonid eggs. Epizootic ulcerative syndrome, caused by *Aphanomyces invadans*, has been reported from 24 countries on four continents, and movements of live fish from EUS-infected countries may spread the disease (107), although flooding has also caused the spread of EUS in neighbouring countries (67).

Movements of infected fish also represent the main mode of transmission for spring viraemia of carp (SVC), which is often found in ornamental fish (109). Even legally imported consignments with appropriate health certification declaring freedom from SVC have been reported to test positive for the virus, as shown recently with goldfish imported into the United Kingdom (UK) (113).

Infectious salmon anaemia virus (ISAV) has probably been spread over long distances by transportation of infected smolts or by contaminated well boats (75, 108). Molecular analysis indicates that the introduction of ISAV into Chile (35) was from Norway (55), probably through fertilised salmon eggs (97). The parasite *Gyrodactylus salaris* has spread between rivers and farms mainly by the transport/restocking of live salmonid fish (52).

Long-distance transport can also play an important role in the emergence of novel diseases when pathogens are introduced to a new environment. One example is *Anguillicoloides crassus* (a nematode infection), which was introduced to Europe through the importation of Asian eels (*Anguilla japonicus*) (56) and has probably played a part in the decline of European eel (*A. anguilla*) numbers over the last 20 years.

The exposure route is important in the introduction of new diseases that may be carried in live animals or contaminated products. For instance, in 1995 and 1997, a herpesvirus caused mortalities of up to 70% in the pilchard *Sardinops sagax* population along the Australian and New Zealand coasts. The virus probably originated from wild-caught fish imported as feed for tuna rearing, although the exact source is still in doubt (33, 53). It has subsequently become endemic (103). Trash fish have also been suggested as the source of betanodavirus and viral nervous necrosis infection for marine cultured fish in Japan (36).

Few reports have linked a disease outbreak to the importation of products. Elston (22) speculated that at least one introduction of *M. cerebralis* to the United States was due to the importation of rainbow trout carcasses. Imported rainbow trout carcasses were also the most likely source of a VHS virus outbreak in the UK in 2006 (92). There is clearer evidence that sleeping disease (40) was introduced into the UK with rainbow trout carcasses from Europe, into a fish farm linked to package processing (12). It should be noted, though, that in these cases it has been difficult to definitively identify the source of the outbreak.

Risk assessments have generally concluded that the movement of products carries a low risk of disease transmission. For example, it was concluded that the risk of spread of infectious haematopoietic necrosis associated with the movement of processed (trout) products from an endemic area was negligible, despite the large volume traded (60). Similarly, Pharo and MacDiarmid (81) concluded from a quantitative analysis that the risk of *Aeromonas salmonicida* introduction into New Zealand with the importation of salmon for human consumption was also negligible.

Non-bivalve molluscs

According to the OIE (110), withering syndrome in abalone (*Haliotis* spp.), caused by *Xenohaliotis californiensis*, probably has a broad geographical range, as infected abalone have been transported to Chile, the People's Republic of China, Iceland, Ireland, Israel, Japan, Spain, Thailand, etc. Furthermore, *X. californiensis* has recently been isolated from *H. diversicolor* in China, Chinese Taipei and Thailand, and this may be linked to historical imports from California (101). In addition, abalone viral mortality, possibly caused by a herpesvirus, is thought to be spreading in the Asia-Pacific region through the movement of broodstock (4).

A previously unknown herpes-like virus was identified in 2006 as being the most likely cause of mass mortalities of abalone (*Haliotis* spp.) in a number of aquaculture farms and wild stocks in Victoria, Australia (34). It was concluded that high-risk pathways for further spread of the disease (abalone viral ganglioneuritis) included movements of infected stock within and between wild and farmed stocks (47).

Bivalve molluscs

Renault (84) showed that the frequent introduction of economically important shellfish into new areas has resulted in the introduction of pathogens that have caused mass mortality among native stocks.

Haplosporidium nelsoni was first identified in 1993 in the Pacific oyster, *C. gigas*, in France (86) but may have been present since 1988 (14). However, it is likely that the parasite was introduced with spat and adult oysters imported from Japan and Canada (British Colombia), respectively, in the 1970s to replace the culture of Portuguese oysters, which had been devastated by a viral disease (37). Nevertheless, the presence of *H. nelsoni* has not been associated with mass mortality in France.

Bonamia ostreae was most probably introduced to France and Spain in the late 1970s and early 1980s through importing the spat of the European flat oyster, *Ostrea edulis*, produced in hatcheries in California (15, 84). *Ostrea edulis* was introduced from the Netherlands onto the west coast of the United States at the end of the 1940s (68). Therefore, the parasite was introduced to Europe not with an exotic species but through reintroduction of a native species from outside its natural geographic range. Following its introduction into Europe, the parasite rapidly spread through shellfish production areas and natural beds, due to both authorised and illegal movements of stock. The consequences were catastrophic and European flat oyster production was dramatically reduced. It has never recovered. Transfer of the parasite to wild stocks was observed and natural beds suffered high mortality.

Perkinsus olseni was probably transported from Asia to Europe by the movement of Manila clams, *Tapes philippinarum*, for aquaculture (46), and in 2008 it was diagnosed in aquacultured giant clams imported from Vietnam to the United States for research purposes (96).

Summer mortality episodes in *C. gigas* have occurred for many decades in oyster-producing countries such as Australia, France, Japan and the United States (88). These mortalities have been linked to the presence of the ostreid herpesvirus 1 (OsHV-1) in France (19), although the combination of environmental factors and bacteria of the genus *Vibrio* may also play a role (59). It is speculated that the virus may have resulted from interspecies transmission from the introduction and intensive culture of non-native bivalve species (3, 48). The early problems in the United States, in the 1950s, followed the importation of oysters for aquaculture (88) and, more recently, a similar herpesvirus has been recorded in association with mortalities on the west coast (29). In 2008 and 2009, OsHV-1 (μvar) was reported to have caused further high-mortality outbreaks in Pacific oysters in France, Ireland and the Channel Islands, as well as in the UK in 2010 (112). It was considered that movements of infected seed stock from France were associated with these mortalities, at least in the early outbreaks (70, 95).

High-density bivalve production, including that from commercial hatcheries and nurseries, is therefore an important source of viral diseases in aquaculture and the movement of stock must be considered as posing one of the major risks of disease spread (85, 89).

Crustaceans

White spot syndrome virus is by far the most devastating pathogen of farmed shrimp. White spot disease was first reported in June 1992 in cultured kuruma shrimp (*Penaeus japonicus*) in Fujian Province in China, and in nearby Chinese Taipei (50, 116). From March 1993, outbreaks were reported in several prefectures in Japan, starting in farms that had imported *P. japonicus* juveniles from China (76). By 1994, WSSV had spread to most shrimp-farming countries throughout South and Southeast Asia. The rapid spread of WSSV was attributed largely to irresponsible movement of post-larvae and broodstock between countries. The first recorded outbreak of WSSV in the Americas was at a farm in Texas, in November 1995. A nearby processing plant that imported frozen shrimp from Asia may have been the source (20, 66), although Flegel (26) recently considered this claim to be speculative. In 1997 and 1998, WSSV was detected in wild prawn stocks in South Carolina and Texas. The major epidemic of white spot disease in the Americas began in Nicaragua, Honduras and Guatemala in mid-January 1999. Subsequently, the disease was reported in Panama in March, Ecuador in May and had reached Peru by October 1999 (1). It is now endemic throughout much of Central and South America. Infectious hypodermal and haematopoietic necrosis virus (IHHNV) is also believed to have been introduced to the Americas in the 1980s by importing live experimental stocks of the black tiger shrimp, *P. monodon,* from Asia. The virus was subsequently discovered in blue shrimp (*P. stylirostris*) and white shrimp (*P. vannamei*) (62, 63, 64).

Taura syndrome was first reported in farmed white Pacific shrimp (*P. vannamei*) near the mouth of the Taura River in Ecuador, in June 1992 (51). By 1996, Taura syndrome virus had spread to Peru and north-eastern Brazil, throughout the Pacific and Caribbean coasts of Central America, and to Florida and Texas in the United States (61). In 1998, Taura syndrome virus spread to Chinese Taipei in *P. vannamei* broodstock imported from Central and South America (94, 115). By 2004, following the dramatic increase of *P. vannamei* production, the virus had become endemic in most major shrimp-farming countries in East and Southeast Asia (77). The rapid spread of the virus has been attributed to international trade in post-larvae and broodstock (13, 87, 94).

Infectious myonecrosis (IMN) was first recognised in September 2002 in farmed *P. vannamei* in north-eastern Brazil (65). By 2004, IMNV had spread to other regions of Brazil and was subsequently detected in *P. vannamei* collected from an outbreak in East Java in Indonesia in May 2006 (90). It is likely that the virus was introduced to Indonesia in broodstock imported from Brazil.

As far as shrimp products are concerned, Flegel (25) reviewed the literature on the spread of shrimp diseases and concluded that, whilst the theoretical possibility of transmission via shrimp products had been demonstrated, there were no published reports of outbreaks being traced to imported shrimp products. Nevertheless, the virus can be isolated from imported shrimp products bought at retail outlets (20, 66). However, Sritunyalucksana *et al*. (91) showed that the risk of yellow head virus transmission from commodity shrimp is reduced to negligible levels by normal processing.

Crayfish plague, caused by *Aphanomyces astaci* and carried asymptomatically by the native signal crayfish (*Pacifastacus leniusculus* Dana 1852), is thought to have been brought to Europe from North America in about 1860 when mortalities occurred in Italy (21). Native European crayfish (*Astacus astacus* L.) have no resistance to the fungus and infections are invariably fatal, to the extent that, in affected rivers, populations are wiped out. The disease risks presented by the movement of signal crayfish were not recognised originally because the parasite caused no disease within its original geographic range or host species. It is considered that one of the main routes of spread of the pathogen is through the movement of infected crayfish (either the highly susceptible species or North American crayfish species), and in Europe, where the fungus is now widespread, this has been linked to the active stocking of North American crayfish into the wild or escapes from crayfish farms (106).

Amphibians

Recent evidence, reviewed by Fisher and Garner (24), implicates the world trade in amphibians in the recently emerged disease chytridiomycosis, caused by the fungus *Batrachochytrium dendrobatidis*. These authors further indicate that the amphibian trade is driving the emergence of chytridiomycosis by spreading infected animals worldwide. Thus, human-mediated transport of infected amphibians is the most plausible cause of the intercontinental spread of chytridiomycosis, responsible for amphibian population declines and extinctions in many countries (57). Garner *et al*. (30) state that infection with *B. dendrobatidis*, and other important amphibian pathogens, such as ranaviruses, has been detected in amphibians traded for food, the pet trade, and research (24, 49, 79, 82), and a link between trade, the introduction of non-native amphibian species and disease emergence in wild amphibian populations has been postulated (24, 100). Ranaviruses and *B. dendrobatidis* have also been shown to occur in wild-caught tiger salamanders, used for bait by fishers in the United States (82). Ranaviruses also infect fish (e.g. epizootic haematopoietic necrosis virus) and have the ability to switch hosts (83). It has been considered that localised frog mortalities in the UK were caused by such a virus, imported from the United States in bullfrogs and goldfish destined for the pet trade (17). More recently, it has been shown that ranavirus infection may have caused long-term declines in the common frog (*Rana temporaria*) (93).

Considering the possibility of transfer of pathogens, especially viruses, between fish, amphibians and reptiles, it is important to understand the pathways of such transfers amongst unrelated species in the aquatic environment.

International aquatic animal health standards

Current standards

Preventing the spread of animal disease through international trade of animals and animal products is one of the primary missions of the World Organisation for Animal Health (OIE). This is accomplished by establishing and updating international standards and guidelines to minimise the spread of pathogens while avoiding

Table IV
Summary of the World Organisation for Animal Health aquatic animal health standards

Horizontal standards [a]	Vertical standards [b]
Import risk analysis	Notification of disease outbreaks
Surveillance	Diagnosis (for each listed disease)
Assessment of the quality of aquatic animal health services	Import and export procedures and health certification
Disease prevention and control	Disinfection of aquaculture facilities
Animal welfare	Disinfection of eggs
Public health	Establishment of pathogen-free zones and compartments
Laboratory quality management	

a) Standards on general animal health issues
b) Disease-specific standards

unjustified sanitary barriers (104). Standards are listed in Table IV.

The OIE standards for aquatic animals are published in the *Aquatic Animal Health Code* (the *Aquatic Code*) and the *Manual of Diagnostic Tests for Aquatic Animals* (the *Aquatic Manual*). The aim of the *Aquatic Code* is to ensure the sanitary safety of international trade in aquatic animals and their products (105). The *Aquatic Manual* provides a standardised approach to the diagnosis of listed diseases, as well as dealing with health certification for trade in aquatic animals and their products (111).

The standards developed by the OIE are recognised as international standards for animal health and zoonoses by the Agreement on the Application of Sanitary and Phytosanitary Measures of the World Trade Organization (104).

In addition to the global standards prescribed by the *Aquatic Code*, one can find regional (e.g. EU) or country-specific (e.g. Australia, the United States, Canada) standards to reduce the risk of pathogen introduction (9). Many of these standards are based on risk analyses and reflect the nature of traded commodities and the status of aquatic animal health in exporting countries and trading partners.

A need for additional standards?

The international spread of aquatic animal diseases through the movement of animals and their products remains a serious issue, despite the current standards. This raises the question of whether the current standards are being fully implemented or whether they are not robust enough in the face of the sheer scale of trade globalisation, and whether, therefore, additional standards are required.

In many countries, the current level of surveillance and disease reporting for emerging diseases of wild and cultured aquatic animals is not fully satisfactory – as has also been pointed out by Kuiken *et al.* (58) for zoonotic infections of terrestrial animals. Consequently, there is a strong need to develop further comprehensive national aquatic animal health strategies to enable compliance with OIE standards to support responsible international trade in aquatic animals and their products.

However, it is the uncertainty of unidentified disease agents that probably poses the greatest risk when aquatic animals are translocated. Such disease agents are often not identified in their region of origin because they cause subclinical disease there, but major disease outbreaks can occur when the agent enters a new habitat, region or naïve population. In many cases, it will not be known whether aquatic animal species in the importing country are susceptible to the pathogens that imported animals may carry, or whether the imported animals are susceptible to resident pathogens. Up-to-date information on disease status is vital to enable a country to mount a rapid response to newly developing disease situations. Although the OIE advises immediate notification of potential emerging disease (105), additional standards on syndromic surveillance are needed for the early detection of emerging diseases, based on signals and disease trends. Improved standards would help to reduce the time between the discovery of a pathogen in a new host species or new geographical area and the appropriate characterisation of the disease threat. At present, this process can take several years, as has been shown with KHV in cyprinid fish and, more recently, with OsHV-1 in oysters or IMN in shrimp. In some cases this reaction is too slow to prevent major problems from developing. This is largely due to a lack of data-gathering and analysis, linked to the poor availability of reliable data sources. At the same time, to list diseases that do not meet the listing criteria, as a precautionary measure, can be a disadvantage for exporting countries, especially if the exporting country does not have the infrastructure to perform diagnoses or mount surveillance programmes. For example, several formerly OIE-listed diseases (e.g. monodon baculovirus infection) have now been de-listed, as they did not meet existing listing criteria. However, it should be borne in mind that the primary purpose of 'listing' is for notification, and not for 'safe trade'. Therefore, the list of notifiable diseases does not necessarily completely match the diseases for which 'trade recommendations' (in the form of the *Aquatic Code* chapters) are provided. The very fact that a disease is listed by the OIE can make a country feel justified in requiring import measures for that disease, regardless (E.-M. Bernoth, personal communication).

Considering the large volumes of dead products traded, the concept of 'safe commodities' has recently been introduced by the OIE. These are commodities for which, when authorising import or transit, competent authorities should not impose any conditions relating to the disease in question, regardless of the status of the exporting country for that disease. This concept was introduced to provide better guidance to OIE Members on commodities that can be traded safely, and also to better reflect the realities of trade. For all other commodities potentially contaminated with infectious disease agents, it is important that importing countries should not simply reject consignments because they are deemed 'too risky', but should assess the risk according to OIE guidelines and, whenever possible, reduce it to an acceptable level. The disease-specific risk management measures will depend on the status of the exporting country for a particular disease but will also take into account the intended final use of the traded commodity (e.g. release into aquaculture facilities or direct human consumption). All the disease chapters in the *Aquatic Code* now provide lists of commodities that are *safe* (that is, for which there should be no restrictions for the disease under consideration); commodities for which certain measures are recommended; and commodities that require risk analysis.

Nevertheless, since trade in aquaculture animals and their products is predicted to increase, the *Aquatic Code* should perhaps reflect this situation and include more 'horizontal' standards, which consider standards by products traded (e.g. live fish, eggs, fillets, fomites), as an alternative to assessing product safety for each disease. Countries trade in commodities, not pathogens, and there is an argument that OIE standards should therefore be commodity-based, reflecting the risk associated with each type of product (E.-M. Bernoth, personal communication). This approach would move import risk analysis away from its current aetiological focus (54), which fails to account for unidentified hazards (32), such as diseases which emerge as a result of non-native species introductions (80). Whittington and Chong (102) make the same point in their comments on the inadequacy of the current import risk analysis standards to assess the disease risks associated with the trade in ornamental aquatic animals. The large number of species originating from many sources, combined with a lack of knowledge of the pathogens and parasites (compared with aquaculture species), critically constrains the import risk analysis process. As a result, they suggest that trade should be limited to selected species and sources.

However, the creation of new or additional standards may only partially solve the problem, since the implementation of the standards themselves and subsequent compliance are also very important. The capacity to implement the standards (see Table IV) is also essential and this can only be achieved through initiatives from a standard-setting organisation towards a holistic approach directed to national governments and international agencies, as well as a determined effort to implement training and capacity-building exercises. This approach would involve a greater focus on international cooperation to deal with threats at source (98). Any proposed change to improve horizontal standards would need to involve the OIE, as the relevant standard-setting organisation, as well as consider the views of the end users, regulatory authorities and the production sector.

Conclusion

There is ample evidence that the trade in live aquatic animals has led to the spread of diseases, particularly when exotic pathogens are transferred and released into susceptible naïve populations. What is not so clear is the role of aquatic animal-derived products in the same process, although it is generally considered that processed (e.g. frozen, dried, salted) products pose a very much lower risk than the direct movement of live animals. Nevertheless, there is a need to identify and mitigate all the potential routes that pathogens could use for trade-based transmission, and this approach should be based on the use of sound epidemiological analytical studies in conjunction with risk analysis. The current limitations of import risk analysis for both products and live animals provide a stimulus to the development of commodity-based standards that will reduce the reliance on such *ad hoc* analyses.

There are data gaps for emerging diseases, due to the fact that they are not usually considered in routine (non-statutory) surveillance programmes. In addition, even the current standards may have compliance problems, particularly in developing countries, due to a lack of capacity for implementation and insufficient diagnostic expertise, related to the availability of resources and training, respectively. Consequently, although data exist for notifiable diseases within most well-developed trading blocks, a more holistic approach is needed to deal with risk-based threats at source. Therefore, the OIE has a role to play in developing standards for syndromic surveillance for the detection of emerging diseases.

Numerous strategies, including quarantine, as well as trade restrictions, aim to control the spread of disease by restricting the interactions between infectious agents, hosts, vectors and environmental reservoirs (42). However, there is still spread of aquatic animal diseases and it can be questioned whether these restrictions have been particularly effective at a global level. Further studies are needed to assess the efficacy of current strategies. There is a corresponding need for improved risk mitigation, since the expansion of aquaculture to meet the increasing demands for animal protein from a growing human population (10) is likely to put further pressure on the existing standards. Continued diversification of species will mean an increased risk of the introduction and spread of transboundary pathogens, and the expansion and intensification of farming will also increase the risk of disease emergence.

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La dissémination d'agents pathogènes lors des échanges internationaux d'animaux aquatiques et de leurs produits

C.J. Rodgers, C.V. Mohan & E.J. Peeler

Résumé

Le rôle du commerce international d'animaux vivants dans la propagation transfrontalière des maladies animales est bien connu, de même que ses conséquences parfois dramatiques lorsque cela se traduit par un élargissement du spectre d'hôtes des agents pathogènes à de nouvelles espèces. À l'heure actuelle, le commerce d'animaux aquatiques s'intensifie et l'aquaculture est en pleine expansion afin de répondre à la demande de plus en plus importante des populations mondiales en protéines d'origine animale. Il ne fait aucun doute que l'aquaculture a permis aux agents pathogènes et aux maladies d'atteindre de nouvelles régions, en leur ouvrant des voies inédites d'introduction et de propagation. On considère généralement que le risque de dissémination de pathogènes associé aux transferts d'animaux aquatiques vivants est plus important que celui associé aux échanges de produits transformés et morts. Le principe des normes sanitaires actuelles consiste à minimiser le risque de maladie et d'incursion des agents pathogènes, tout en évitant de dresser des obstacles injustifiés au commerce. Toutefois, en dépit de ces normes, les mouvements d'animaux sont encore responsables de la propagation internationale de certaines maladies. Les auteurs examinent les liens avérés entre les échanges internationaux d'animaux aquatiques et de leurs produits dérivés, d'une part, et la transmission et la propagation de maladies, d'autre part. Ils rapportent plusieurs exemples de transferts d'agents pathogènes à l'origine de la propagation de maladies et considèrent également le cas des maladies émergentes. Ils concluent à la nécessité d'adopter une démarche holistique afin de s'attaquer à ces menaces à la source, en considérant tous les facteurs de risque.

Mots-clés

Agent pathogène – Animal aquatique – Commerce international – Maladie des animaux aquatiques – Normes sanitaires – Propagation transfrontalière.

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Propagación de agentes patógenos por el comercio de animales acuáticos y sus derivados

C.J. Rodgers, C.V. Mohan & E.J. Peeler

Resumen

Es bien sabido que la propagación transfronteriza de enfermedades infecciosas se ve favorecida por el comercio de animales vivos, y que puede tener graves consecuencias si, a raíz de ahí, un patógeno logra asentarse en una nueva especie anfitriona. El comercio en especies de animales acuáticos va en aumento, y la acuicultura también se está intensificando para responder a la demanda de proteínas animales de una población humana cada vez más numerosa. Por otra parte, está claro que la acuicultura ha abierto rutas inéditas por las cuales los patógenos y las enfermedades pueden introducirse o propagarse en nuevas zonas. En general se considera que el riesgo de transferencia de un agente patógeno es mayor cuando se desplazan animales acuáticos vivos que cuando se trata de animales muertos o de sus derivados. Las normas sanitarias vigentes parten de la idea de reducir al mínimo el riesgo de enfermedad y de penetración de patógenos evitando al mismo tiempo la imposición de barreras injustificadas o innecesarias al comercio. Sin embargo, a pesar de tales normas, se siguen produciendo casos de propagación internacional de enfermedades a resultas del movimiento de animales. Los autores examinan por consiguiente las pruebas que relacionan el comercio internacional de animales acuáticos y sus derivados con la transmisión y propagación de enfermedades. También exponen ejemplos de transferencias de patógenos que han resultado en la diseminación de enfermedades y examinan la situación de las enfermedades emergentes, así como la necesidad de trabajar desde planteamientos holísticos para reducir en su origen las amenazas que es posible cuantificar en forma de riesgo.

Palabras clave

Animal acuático – Comercio internacional – Enfermedad de los animales acuáticos – Normas sanitarias – Patógeno transfronterizo.

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