

Emerging viral diseases of fish

Important emerging viral pathogens of fish are found among many families of vertebrate viruses that are well-known to include pathogens of humans or domestic livestock. However, there are significant differences between the ecology of viral diseases of fish and those of humans or other terrestrial vertebrates. The most significant amongst these differences are that:

- (i) few fish viruses are known to be vectored by arthropods;
- (ii) water is a stabilizing medium, but currents are less effective for long range virus transmission than are aerosols;
- (iii) wild reservoir species are often at very low densities (except for schooling and aggregate spawning stocks);
- (iv) fish are poikilotherms and temperature has an exceptionally critical role in modulating the disease process by affecting both the replication rate of the virus as well as the host immune response and other physiological factors involved in resistance;
- (v) few fish viruses are transmitted sexually between adults, although high levels of some viruses are present in spawning fluids and a few viruses are transmitted vertically from adult to progeny, either intra-ovum or on the egg surface. However, as occurs for avian diseases, migratory fish can serve as carriers for longrange dispersal of viral pathogens.

The global expansion of finfish aquaculture and accompanying improvements in fish health surveillance has led to the discovery of several viruses that are new to science. Many of these are endemic among native populations and opportunistically spill-over to infect fish in aquaculture facilities. Other well-characterized fishviruses (e.g., channel catfish virus, *Onchorhynchus masou* virus) can also cause significant losses in aquaculture but do not seem to be increasing significantly in host or geographic range. In the following sections, we consider the major emerging fish virus diseases that cause significant losses in aquaculture and are expanding in host or geographic range. Because of the risk of spread through commercial trade in finfish, many of the diseases are listed as notifiable by the World Organization for Animal Health (OIE).

1. Infectious haematopoietic necrosis

Infectious haematopoietic necrosis is one of three rhabdovirus diseases of fish that are listed as notifiable by the OIE. Originally endemic in the western portion of North America among native species of anadromous salmon, infectious haematopoietic necrosis virus (IHNV) emerged in the 1970s to become an important pathogen of farmed rainbow trout (*Oncorhynchus mykiss*) in the USA. Subsequently, the virus was spread by the movement of contaminated eggs to several countries of Western Europe and East Asia, where it emerged to cause severe losses in farmed rainbow trout, an introduced species. Similar to other members of the genus *Novirhabdovirus* in the family *Rhabdoviridae*, IHNV contains a negative-sense, single-stranded RNA genome, approximately 11 000 nucleotides in length and encoding six proteins, packaged within an enveloped, bullet-shaped virion.

Isolates of IHNV from North America show a strong phylogeographic signature with relatively low genetic diversity among isolates from sock-eye salmon (*Oncorhynchus nerka*) inhabiting the historic geographic range of the virus. However, isolates from trout in Europe, Japan or Korea, where the virus is emerging, show evidence of independent evolutionary histories following their initial introduction. The emergence of IHNV in rainbow trout aquaculture is accompanied by genetic changes that appear to be related to a shift in host specificity and virulence.

2. Viral haemorrhagic septicaemia

Viral haemorrhagic septicaemia (VHS) is another emerging disease caused by a fish rhabdovirus. Similar to IHNV in morphology and genome organization, viral haemorrhagic septicaemia virus (VHSV) is also a member of the genus *Novirhabdovirus*. The virus was initially isolated and characterized in Europe where it had become an important cause of loss among rainbow trout reared in aquaculture.

Prior to the 1980s, VHSV was assumed to be largely endemic among native freshwater species of fish in Western Europe where it spilled-over to the introduced, and presumably more susceptible, rainbow trout. Subsequently, an increasing number of virological surveys of anadromous and marine fish in the North Pacific and North Atlantic Oceans revealed a much greater host and geographic range than previously recognized, and VHSV was shown to cause significant losses in both cultured and free-ranging species of marine fish. The understanding that VHS appeared to be an emerging disease of marine fish as a result of both greater surveillance efforts and the development of novel forms of marine fish aquaculture was further extended when VHS emerged for the first time in the Great Lakes of North America. The explosive losses among free-ranging native species revealed how devastating the disease can be when first introduced into naive populations of freshwater fish.

3. Spring viraemia of carp

Spring viraemia of carp (SVC) is also caused by a fish rhabdovirus (SVCV). However, unlike IHNV and VHSV, SVCV is related to rhabdoviruses in the genus *Vesiculovirus* in having an enveloped, bullet-shaped virion with somewhat shorter morphology and lacking the non-virion gene characteristic of *Novirhabdovirus*. Initially believed to be endemic among common carp (*Cyprinus carpio*) in Eastern and Western Europe, the disease appeared in the spring to cause large losses among farm-reared carp. More recently, SVCV has emerged in several regions of the world where it has been associated with very large losses in common carp and its ornamental form, the koi carp. These outbreaks have occurred in both farmed and wild fish, suggesting a recent range expansion. The emergence of SVC in North America, Asia and in portions of Europe, formerly free of the virus, appears to be a result of both improved surveillance and the global shipment of large volumes of ornamental fish, including koi carp. Genotyping of isolates of SVCV and a closely related fish rhabdovirus from Europe, pike fry rhabdovirus, from various locations have revealed the isolates form four major genetic clades, and that the isolates of SVCV representing the recent emergence and geographic range expansion appear to have links to the spread of the virus within China where common carp are reared in large numbers for food and koi are reared for export.

4. Infectious salmon anaemia

Infectious salmon anaemia (ISA) is an emerging disease of farmed Atlantic salmon (*Salmo salar*) caused by a member of the family *Orthomyxoviridae*. The virus (ISAV) has eight independent genome segments of

negative-sense, single-stranded RNA packaged within a pleomorphic, enveloped virion, approximately 100–130 nm in diameter, and is the type species of the genus *Isavirus*. Initially identified as the causative agent of outbreaks and high rates of mortality among Atlantic salmon reared in sea cages

in parts of Norway, ISAV subsequently emerged to cause losses in other areas of Western Europe where Atlantic salmon are farmed.

The virus was also confirmed to be the cause of an emerging hemorrhagic kidney disease of farmed Atlantic salmon along the Atlantic coast of Canada and the USA. Isolates of ISAV form two major genotypes containing isolates from Europe and North America, respectively. More recently, ISAV has caused very extensive losses in the Atlantic salmon farming industry in Chile. Genetic analysis has revealed that the Chilean isolates group with those from Norway and that the virus was likely transferred to Chile sometime around 1996 by the movement of infected eggs [63]. Although principally known as a pathogen of Atlantic salmon, ISAV has been isolated from naturally infected marine species that are apparent reservoirs for virus spill-over to susceptible Atlantic salmon in sea cages. Investigation of virulence determinants of ISAV has also revealed significant differences among isolates. Thus, the emergence of ISA appears to be a response to the farming of a susceptible species in an endemic area, evolution of the virus and some degree of transmission via the movement of fish or eggs used in aquaculture.

5. Koi herpesvirus disease

The disease caused by koi herpesvirus (KHV) is amongst the most dramatic examples of an emerging disease of fish. KHV is a member of the genus *Cyprinivirus* in the family *Alloherpesviridae*. Koi herpesvirus disease is relatively host-specific; although other cyprinid species have been shown to be susceptible, only common carp (*C. carpio*) and its ornamental subspecies, the koi carp, have been involved in the explosive losses that have been reported globally in areas where the virus has been first introduced. The enveloped virion of KHV, formally classified as the species *Cyprinid herpesvirus 3*, has a morphology typical of herpesviruses and contains a double-stranded DNA genome of approximately 295 kbp. Molecular analysis has shown little variation among isolates, as might be expected for a virus that is being rapidly disseminated by the global movement of infected fish; however, minor variation has been reported that may reflect at least two independent introductions or emergence events of KHV.

A significant problem is that once fish are infected, the virus persists for some period of time in a latent or carrier state without obvious clinical signs. It appears that the movement of such carriers via the extensive trade in cultured ornamental fish has resulted in the rapid appearance of the disease in many regions of the world. In addition, the release or stocking of ornamental fish into ponds and other natural waters has resulted in the introduction of KHV to naive wild populations, where the initial exposure can result in substantial mortality.