Pergamon

Annual Review of Fish Diseases, Vol. 4, pp. 375-388, 1994

0959-8030/94 $24.00 + .00

0959-8030(94)00004-2

VIRAL INFECTIONS OF AQUATIC ANIMALS WITH SPECIAL REFERENCE TO ASIAN AQUACULTURE

W. Ahne
Institute of Zoology, Fishery Biology and Fish Diseases, University of Munich,
Kaulbachstrasse 37, 80539 München, Germany

Abstract. Worldwide, the number of communicable diseases of animals raised in aquaculture continue to increase. Viral infections of cultivated shellfish, crustacea, and finfish have been frequently recognized in the past few years. In the Asian regions, penaeid shrimp and several teleost fish underwent epizootics associated with heavy losses in aquaculture. Baculoviruses are particularly harmful to shrimp and prawns. Herpes-, irido-, reo-, or rhabdovirus-like agents can cause outbreaks in fish farms. Viral diseases are important limiting factors in the expansion of aquaculture. However, studies on viral infections of aquatic animals have been focused primarily on economically important farmed fish. Therfore, certain viral diseases of teleost fish are relatively well understood. In contrast, our knowledge of viral infections of farmed aquatic invertebrates is still very spare. Although a great number of viruses have been detected in farmed molluscs and crustaceans, the pathogenicity and epizootiology of most of the agents is not known.

Keywords. Aquaculture, Viral infections, Viral diseases of fish, Crustacea and bivalve mollusc, Fish viruses, Mollusc viruses, Crustacea viruses, Baculoviruses, Enteroviruses

INTRODUCTION

Viruses of the aquatic environments infecting poikilothermic animals (Fig. 1) do not differ in morphology and biochemical composition from viruses in the terrestrial environment infecting homoithermic animals. The present taxonomic system of viruses includes 2430 agents belonging to 73 different families. The classification of viruses is mostly based on the type of nucleic acid, the viral morphology and the hosts being infected (1).

The universal system of virus taxonomy is set at the hierarchic levels of family, genus, and species. A virus family contains of a group of viruses with common characteristics and with possible common evolutionary ancestors generally designated by names ending *-viridae*.

Figure 2 and Fig. 3 provide diagrams of the virus families infecting invertebrates and vertebrates. The figures contain the viral agents which are discussed in the present paper.

Aquaculture has dramatically expanded worldwide during the past decade. Asia is the leading continent in the aquacultural facilities producing about 85% of the world aquaculture harvest. Methods used in mariculture include cage husbandry, sea ranching, and the culturing of mussels using ropes and net cages. In intensive limniculture, freshwater fish are raised at a high density using an artificial diet. An integrated form of fish farming involving fish and domestic animals in close proximity is traditional in Asiatic countries. Today, molluscan aquaculture is rapidly increasing in China, Thailand, and the Philippines; crustacean aquaculture is very important in Japan, Indonesia, and India, and finfish aquaculture is expanding in China, Bangladesh, India, Japan, Thailand, and other countries (2).

Several Asian countries have reported viral infections of shrimps, prawns, and finfish (Table 1). The major communicable diseases of teleost fish are caused by herpes-, irido-, reo-, birna-, and rhabdoviruses. In shrimp and prawn husbandry, baculoviruses cause high mortalities in infected larvae, postlarvae, and juvenile shrimp. The information available on viral infections affecting molluscs is still sparse. However, the bioaccumulation of human enteroviruses by bivalve molluscs may be an important hazard to humans who eat raw or improperly cooked shellfish.

The aim of this article is to provide information about viruses affecting farmed aquatic animals with special reference to Asian aquaculture.

VIRUSES OF FISH

Today, about 60 different viruses have been detected in finfish species; however, only a few cause severe epizootics in aquaculture (Table 2).

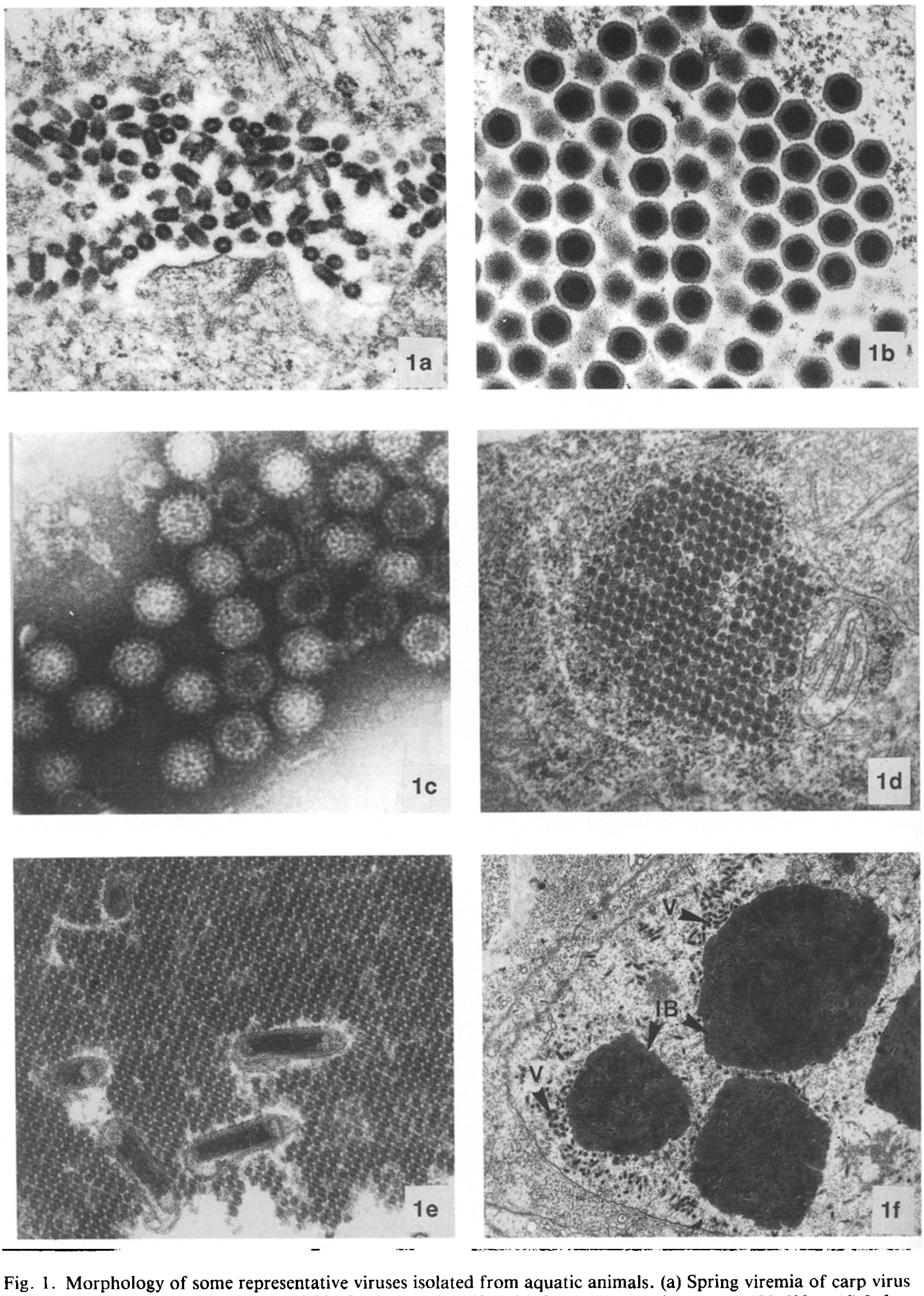

Fig. 1. Morphology of some representative viruses isolated from aquatic animals. (a) Spring viremia of carp virus (SVCV), mag. 43,200×. (b)Sheatfish iridovirus, mag. 37,440×. (c) Grass carp reovirus, mag. 129,600×. (d) Infectious pancreatic necrosis virus (IPNV), mag. 39,600×. (e) *Penaeus monodon* baculovirus maturing in a crystalline inclusion body of hepatopancreas, mag. 64,800×. (f) Free and occluded baculovirus (V) and inclusion bodies (IB) in the nuclei of hepatopancreatic epithelial cells of *Penaeus monodon*, mag. 6,480×.

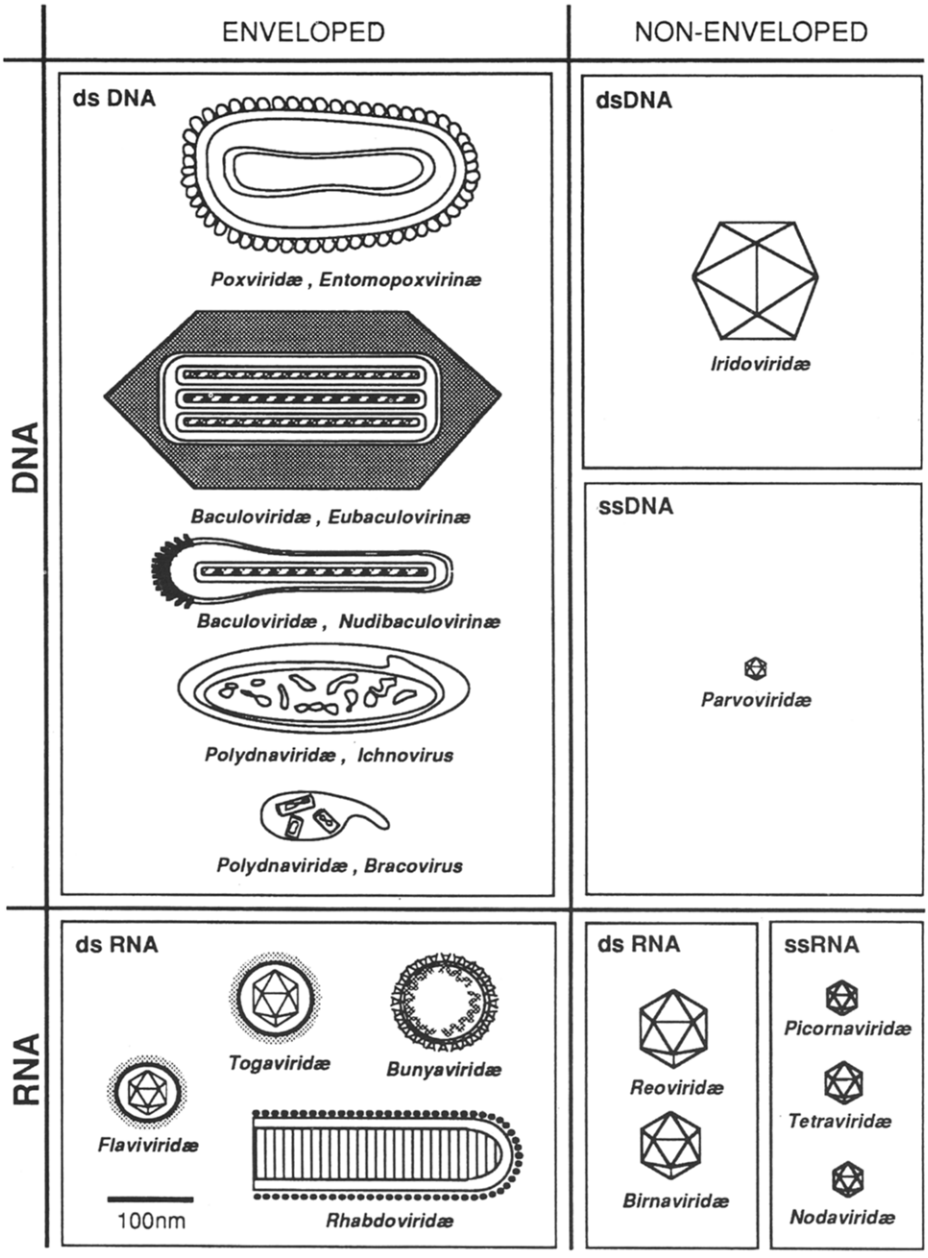

Fig. 2. A diagram showing the virus families infecting invertebrates, ds: double-stranded, ss: single-stranded (Reprinted with permission from [1]).

The pathogenic viruses of fish recognized in Asia include oncogenic herpesviruses (*Oncorhychus masou virus, Herpesvirus cyprini*), benign iridovirus (lymphocystis virus), reovirus (grass carp reovirus), birnaviruses (IPNV-Ab, IPNV-Sp, IPNV-WB), rhabdoviruses (*Anguilla* rhabdoviruses, *Rhabdovirus olivaceus*, infectious hematopoietic necrosis virus, ulcerative disease rhabdovirus), and coronaviruses.

Herpesviridae

Herpesviruses are wide-spread in nature, with most of the agents showing a strong host specifity.

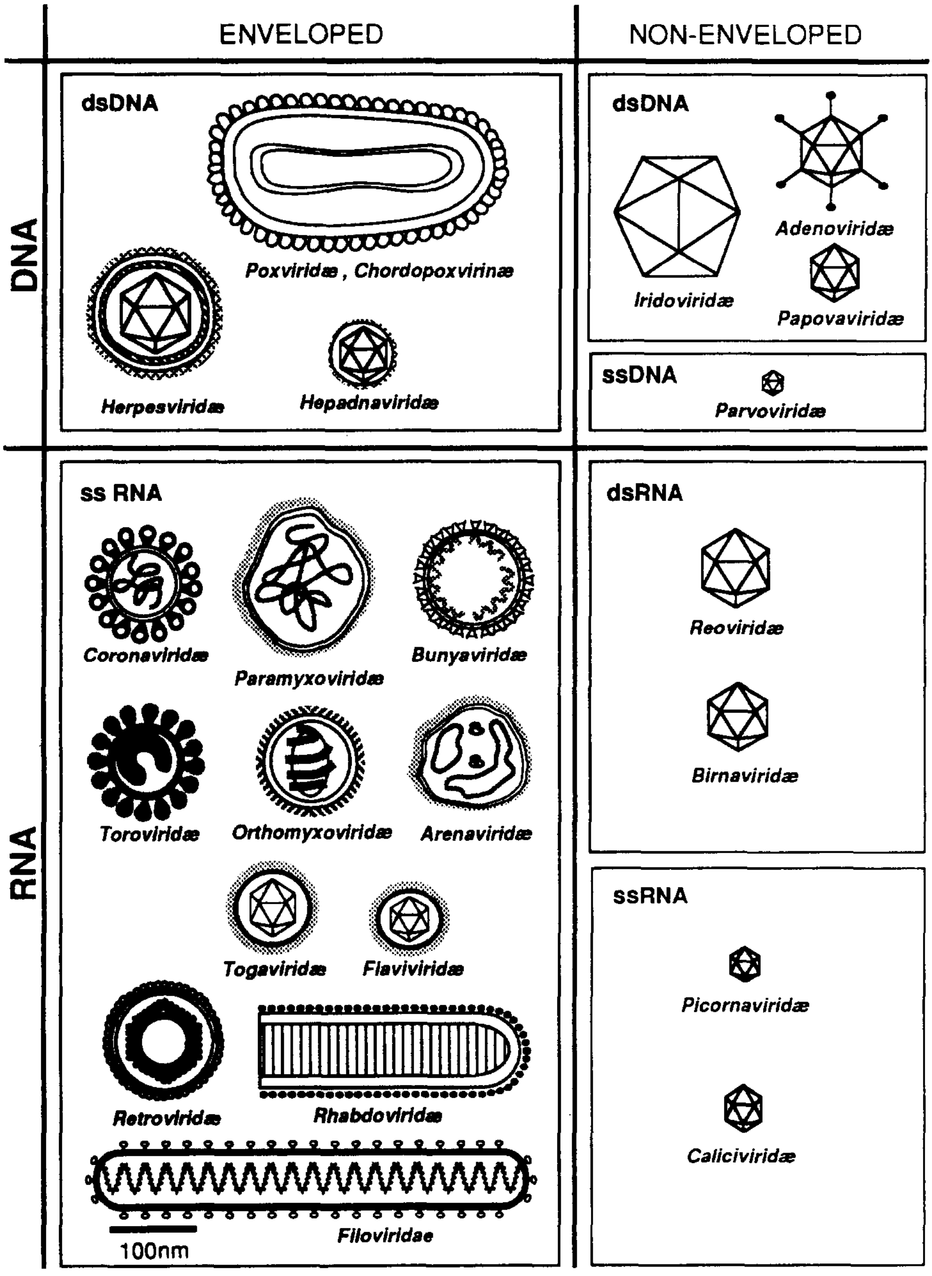

Fig. 3. Line drawing for the virus families infecting vertebrates (Reprinted with permission from [1]).

Several herpesvirus infections of different fish species have been recognized in the past years. Some fish herpesviruses are oncogenic, while others cause systemic diseases associated with mortalities.

Sano, Fukuda, and Sano (3) described herpesvirus-like agents (*Anguilla* herpesviruses) from the Japanese eel (*Anguilla japonica*) and from the European eel (*A. anguilla*). Both induced systemic diseases in infected animals.

Channel catfish herpesvirus (CCV) is the causative agent of a serious disease of channel catfish (*Ictalurus punctatus*) fingerlings in the Southern United States. The virus has been isolated from imported channel catfish fry in Honduras and in Cen-

Table 1. Viruses in Asian aquaculture

Burma	
	Rhabdovirus associated with the ulcerative syndrome of different fish species
China (P.R.)	
	Reoviruses isolated from common carp, grass carp and black carp
	Birnavirus (IPNV-Sp) isolated from rainbow trout
	Aranavirus of fresh water mussels (HcPV)
China (Taiwan)	
	Birnaviruses (IPNV-WB, IPNV-Ab) isolated from rainbow trout and other fish
	Reoviruses isolated from rainbow trout, salmon and hard clam
	Baculoviruses of penaeid shrimps
Japan	
	Herpesvirus cyprini isolated from carp
	Herpesvirus isolated from Japanese eel
	Herpesviruses (OMV, NEVTA, YTV) isolated from masou salmon, kokanee, yamame
	Iridoviruses (VEN, LCV) detected in different fish species
	Rhabdoviruses (eel: EVA, EVX; hirame, ayu: RVO; salmonid fish: IHNV)
	Birnaviruses (IPNV: Ab = EVE from eel; IPNV-WB isolated from salmonids)
	Reoviruses isolated from chum salmon (CSV) and from blue crab
	Papova-, Picorna-, Corona-, Paramyxo- Poxvirus of different fish species
	Baculoviruses of penaeid shrimps
Korea	
	Birnavirus (IPNV-WB, IPNV-Sp) isolated from salmon, trout, goldfish, eel
Malaysia	
	Iridovirus (LCV) detected in different fish species
	Parvo- and reovirus-like agents of penaeid shrimps
Phillipines	
	Baculoviruses of penaeid shrimps
Sri Lanka	
	Rhabdovirus associated with the ulcerative syndrome of different fish species
Thailand	
	Rhabdovirus associated with the ulcerative syndrome of different fish species
	Birnavirus (IPNV-Sp) isolated from snakehead fish and spot barb

tral America (4). However, CCV has not yet been reported in Asia aquaculture.

Epidermal hyperplasia on the fins and skin and degeneration of malpighian cells of Japanese flounder larvae (*Paralichthys olivaceus*) from several Japanese production facilities, have been found to be associated with herpesvirus infection (5,6). Based on the histopathologic findings the disease was named "viral epidermal hyperplasia of flounder larvae."

A herpesvirus was isolated in Japan from fancy carp (*Cyprinus carpio*) having epidermal papillomas. The virus, *Herpesvirus cyprini*, proved to be oncogenic to cyprinid fish (7) and is, most likely, identical to the agent causing the "fish pox" in European cyprinids.

In Japan, four herpesviruses have been found in salmon: (a) Nerka virus (NeVTA) isolated from *O. nerka* (8), (b) *O. masou* virus (OMV) isolated from *O. masou* (9,10), (c) Yamame tumor virus (YTV) isolated from *O. masou* (11), and (d) Coho salmon tumor virus (CSTV) isolated from *O. kisutch* (12). OMV and YTV are oncogenic inducing tumors in masou salmon, chum salmon, coho salmon, and kokanee salmon. The rainbow trout (*O. mykiss*) has also been found to be susceptible to OMV. NeVTA, OMV, and YTV proved to be serologically related, they are distinct from herpesviruses found in salmonid fish in North America (13).

The steelhead trout (*O. mykiss*) showed a 50% postspawning mortality in a trout farm in the USA. The herpesvirus (*Herpesvirus salmonis*) isolated from ovarian fluids of spawners has not been recognized outside the USA (14).

Iridoviridae

Three major types of piscine iridoviruses can be distinguished by their pathogenicity, morphology, and antigenicity: (a) iridovirus associated with hypertrophy of connective tissue cells (lymphocystis-virus), (b) iridovirus-like agents associated with erythrocytic necrosis (ENV), and (c) iridovirus-like agents associated with epizootic haematopoietic necrosis (EHNV).

Lymphocystis disease, a chronic benign viral infection found in more than 140 teleost fish species worldwide, is caused by an iridovirus, the lymphocystis virus. The dermatotropic virus induces hypertrophy of infected cells of skin, fins, and internal organs of finfish. The lymphocystis virus was detected in several marine, brackish water, and freshwater fish species in Asia (Japan), Europe, and the USA (15).

Viral erythrocytic necrosis (VEN) caused by an iridovirus-like agent has been described in a variety of marine finfish worldwide. The disease, characterized by cytoplasmic inclusion bodies in infected erythrocytes, was reported from pink salmon (*O. gorbucha*) and chum salmon (*O. keta*) in Japan (15).

Systemic iridovirus-like infections of several fish associated with hemorrhagic syndrome and high mortalities have been reported in Australia, Japan, and Europe. At least three of the Australian and European agents proved to be serologically related (16).

Table 2. Important viruses in fish aquaculture

Herpesviridae	
Anguilla herpesviruses	Japan
Cannel catfish virus (CCV)	North America
Flounder herpesvirus	Japan
Herpesvirus cyprini	Japan, Europe
Oncorhychus masou virus (OMV)	Japan
(Nerka virus, Yamame tumor virus)	
Coho salmon tumorvirus	Japan
Herpesvirus salmonis	USA
Iridoviridae	
Lymphocystisvirus (LCV)	worldwide
Erythrocytic necrosis virus (ENV)	worldwide
Epizootic haematopoietic necrosis viruses (EHNV)	Australia, Europe
Reoviridae	
Grass carp reovirus	P.R. China
Reovirus of common carp	P.R.China
Reovirus of salmonids	Taiwan
Birnaviridae	
Infectious pancreatic necrosis virus (IPNV)	worldwide
Rhabdoviridae	
Anguilla rhabdoviruses (EVA, EVX)	Japan, Europe
Infectious hematopoietic necrosis virus (IHNV)	Asia, USA, Europe
Hemorrhagic septicemia virus (VHSV)	Europe, USA
Spring viremia of carp virus (SVCV)	Europe
Pike fry rhabdovirus	Europe
Rhabdovirus olivaceus	Japan
Ulcerative disease rhabdovirus	Burma, Sri Lanka, Thailand
Coronaviridae	
Coronavirus of carp	Japan

Epizootic haematopoietic necrosis (EHN), a systemic iridovirus-like disease of redfin perch (*Perca fluviatilis*) was first described in Australia (17). The EHN virus, which causes severe necrosis in the renal and splenic hematopoietic tissue, showed a wide host range including seven teleost fish species (18). Iridovirus-like agents associated with hemorrhagic syndrome and necrosis of hematopoietic tissue were later isolated from moribund sheatfish (*Silurus glanis*) in Germany (19) and from catfish (*Ictalurus melas*) in France (20). It is interesting to note that EHNV, the iridovirus from sheatfish, catfish, and frog virus 3 (the type species of the genus *Ranavirus* of *Iridoviridae*) showed similarities in morphology, size, structural polypeptides, and in antigenicity (16).

Sorimachi (21) reported the isolation of an icosahedral cytoplasmic deoxyribovirus from the Japanese eel (*Anguilla japonica*). The virus was pathogenic to all sizes of Japanese eel with mortality rates reaching 75% within two weeks. Infected eel showed extensive hemorrhages and necrosis of the intestinal tissue of kidney, pancreas, and spleen.

Additionally, a systemic iridovirus-like agent was recognized among diseased chromid cichlid (*Etroplus maculatus*) imported from Singapore to Canada. Infected fish showed a complete replacement of hematopoietic renal interstitial tissue by a heterogenous population of hypertrophic cells. Large amphophilic angular inclusion bodies were present in the nuclei of blast-like cells. Numerous polyhedral irodovirus-like particles of 180–200 nm could be detected in hypertrophic cells in the intestinal lamina propia and the brancial vascular sinus (22).

Reoviridae

A hemorrhagic disease of grass carp (*Ctenopharyngodon idella*) and black carp (*Mylopharyngodon piceus*) was first observed about 20 years ago in China. The disease, which killed approximately 80% of the population of grass carp and black carp fingerlings in China, was associated with a reovirus infection (23,24). The agent isolated from infected grass carp having hemorrhages in muscle and in internal organs represents features of the new established genus *Aquareovirus* of *Reoviridae* (1).

In addition, reovirus-like agents with unknown pathogenicity have been isolated from rainbow trout, landlook salmon in Taiwan (25), and from common carp in China (26).

Birnaviridae

Aquatic birnaviruses, such as the infectious pancreatic necrosis virus (IPNV), have been detected in numerous species of fish and several molluscs (27), shrimp (28), and rotifers (29).

IPNV is an important pathogen of cultured salmonids (27) and eels (8). The agents isolated from a variety of fish species represent a single major serogroup of IPNV. Several IPNV serotypes are limited to certain geographical areas, e.g. USA (IPNV-West Buxton, Wb), Canada (IPNV Canada 1,2,3 and IPNV Jasper), and Europe (IPNV-Ab, IPNV-He, IPNV-Sp, IPNV-Te). Most of the IPNV isolates from finfish and bivalve molluscs in Asia belong to the IPNV-Ab serotype (30). IPNV-Wb- and IPNV-Sp-like isolates have also been detected in Asian aquaculture, but have been restricted to salmonid fish (31-33).

Aquatic birnaviruses from Asiatic aquaculture have not been thoroughly studied and little is known about serological relationships between individual IPNV isolates. The Asian birnavirus "EVE" (Eel Virus European) isolated from the Japanese eel (*Anguilla japonica*) with branchionephritis (34,35) was found to be closely related to IPNV-Ab serotype, but it differed by at least one epitope (36). Several IPNV isolates obtained from aquatic animals (e.g. eel, milkfish, tilapia, perch, and clam) in Taiwan showed a close relationship to the IPNV-Ab serotype. However, one IPNV-like agent isolated from snakehead fish (*Ophicephalus striatus*) in Thailand was closely related to the IPNV-Sp serotype (30,37). In contrast, IPNV isolates from chum salmon (*O. keta*) and goldfish (*Carassius auratus*) in Korea were found to be related to the North American IPNV type Wb (32).

Rhabdoviridae

Rhabdoviruses of fish are usually associated with epizootics and significant losses in aquaculture, primarily in Europe and North America. The rhabdoviruses of fish share characteristics of the genera *Vesiculovirus* and *Lyssavirus* of *Rhabdoviridae*.

Two rhabdoviruses isolated from eel populations being affected by an epizootic hemorrhagic disease in Japan were reported: (a) the eel rhabdovirus American (EVA) from American eel (*Anguilla rostrata*), and (b) the eel rhabdovirus European (EVEX) from European eel (*A. anguilla*) (8,38). The agents representing the vesiculovirus-type were found to be antigenically closely related, but they proved to be distinct from the other known fish rhabdoviruses (39).

Epizootics due to the infectious hematopoietic necrosis virus (IHNV) are, at present, quite common in salmonid aquaculture in the USA and Europe. The presence of IHNV has been demonstrated in Japan (8). The virus, which probably originated from the American Pacific Northwest, may have been introduced into Asia with imported fish eggs or fry. Niu and Zhoa (40) reported an IHN-like outbreak in a trout farm in the People's Republic of China. However, the causative agent has not yet been identified.

The viral hemorrhagic septicemia (VHS), an acute viscerotropic disease of salmoniformes in European aquaculture, is caused by a *Lyssavirus*-type rhabdovirus, the VHS virus (VHSV), and leads to high mortalities (14). The agent was recently detected in the USA, but not yet in Asia.

Spring viremia of carp virus (SVCV), which causes sytemic infections and losses in farmed cyprinids, has been reported in Europe only (14). The pike fry rhabdovirus (PFR), originally described as the causative agent of "red disease" in pikes (*Esox lucius*) (41), has been isolated also from moribund grass carp in Europe (42). However, SVCV and PFR, which are serologically related, have not been detected in Asia, albeit common carp and grass carp were originally introduced to Europe from East Asia.

A rhabdovirus was discovered in Japanese flounder (hirame), (*Paralichthys olivaceus*) and in ayu (*Plecoglossus altivelis*) in Japan (43). The agent, *Rhabdovirus olivaceus*, proved to be pathogenic to Japanese flounder, black sea bream (*Crysophrys major*), black rock fish (*Sebastes inermis*), and rainbow trout (*O. mykiss*). *Rhabdovirus olivaceus*, which exhibited structural proteins closely related to those of the *Lyssavirus*, did not appear to be antigenically related to the other fish rhabdoviruses (44).

Certain fish species in Southeast Asia and the Indo-Pacific region have been affected by ulcerative diseases during the last 10 years. Epizootics of the ulcerative syndrome were obseved in fish associated with rice field cultivation. Over 100 species of freshwater and eustarine fish were reported to be affected by the disease, but the snakehead fish (*Ophicephalus striatus, O. punctatus*), the walking catfish (*Clarias bratachus*), and the sand goby (*Oxyeleotis marmoratus*) appeared to be most susceptible. Several rhabdovirus-like agents have been isolated from infected snakehead fish and other fish species in Burma, Laos, Sri Lanka, and Thailand (45,46). Serum neutralization tests showed no antigenic relationship between the snakehead fish rahbdoviruses and the other major fish rhabdoviruses (47,48). However, the etiology of the widespread ulcerative syndrome of fish is still unclear, but the so called *Ulcerative Disease Rhabdovirus* (UDRV) (45,49) may play a primary role in the outbreak of the disease.

Coronaviridae

Sano, Yamaki, and Fukuda (50) isolated a corona virus-like agent from the common carp (*Cyprinus carpio*) in Japan. The agent replicated in several fish cell lines proved to be pathogenic to carp fry. Mortality rates of 70% occurred 20 days after waterborne infection. Moribund fish revealed hepatic and renal tubular necrosis as well as destruction of the renal hematopoietic tissue.

Other fish viruses. Several virus-like particles which remain to be classified (icosahedral deoxyribovirus, papovavirus-, herpesvirus-, poxvirus-, picornavirus-, reovirus-, paramyxovirus-, and retrovirus-like agents) were detected in different Japanese fish species (e.g. eel, common carp, ishidai, flounder, and bream) (15).

VIRUSES OF BIVALVE MOLLUSCS

The disease-related problems associated with the aquaculture of mussels, oysters, and clams are increasing worldwide (51). Although reports of viral diseases in molluscs are relatively rare, several viruses have been found in different molluscs (Table 3). Many of these viruses may represent single case discoveries only, but some of the agents must be regarded as pathogens responsible for epizootics in mollusc farming.

Table 3. Viruses in bivalve molluscs

Herpesviridae	
Mollusc herpesvirus	*Crassostrea gigas, C. virginica, Ostrea edulis*
Iridoviridae	
Oyster velar virus (OVV)	*Crassostrea gigas*
Hemocytic virus	*Crassostrea gigas, C. angulata*
Papovaviridae	
Mollusc papovavirus	*Crassostrea virginica*
Arenaviridae	
Hyriopsis cumingii plague virus (HcPV)	*Hyriopsis cumingii*
Birnaviridae	
IPNV-like viruses	*Crassostrea gigas, C. virginica, Littoria littorea, Mercenaria mercenaria, Mytilus edulis, Ostrea edulis, Patella vulgata, Tellina tenuis*
Reoviridae	
$13P_2$ virus	*Crassostrea virginica*
Picornaviridae	
Bay mussel picornavirus	*Mytilus edulis*
Retroviridae	
B-type retrovirus	*Mya arenaria*
Bioaccumulation of human enteroviruses	clams, cockles, mussels, oysters

Herpesviridae

Herpesvirus-like agents have been discovered in American oysters (*Crassostrea virginica*) (52), in flat oysters (*Ostrea edulis*) (53), and in Pacific oyster (*Crassostrea gigas*) (54). In the latter case, the herpesvirus infection was connected with mortality rates of up to 100% of the larvae. Furthermore, abnormal morbidity and mortality of hatchery-reared Pacific oyster larvae was associated with herpesvirus infection of connective tissue and mantle epithelium (55).

Iridoviridae

Three iridovirus infections of Pacific oysters (*Crassostrea* species) have been reported. Two iridoviruses were discovered in hemocytes of adult oysters (56), the third was associated with lesions of the velum larvae (57). The oyster velar virus disease (OVVD), which depress production of oyster larvae, is one of the most important viral diseases of marine bivalves.

Papovaviridae

Papovavirus-like agents have been found in the nuclei of hypertrophied cells in gonadal tissue of American oysters (*Crassostrea virginica*) (58). The virus could be involved in oncogenesis of molluscs.

Arenaviridae

Arenavirus infection of the pearl-producing freshwater mussel *Hyriopsis cumingii* was detected in China (59). The disease, known as "Hyriopsis cumingii plaque," is characterized by hydropic degeneration of the digestive gland and epithelial cells of different organs.

Birnaviridae

Birnaviruses were isolated from the digestive tract of various marine bivalves (*Crassostrea gigas, C. virginica, Littorina littorea, Mercenaria mercenaria, Mytilus edulis, Ostrea edulis, Patella vulgata, Tellina tenuis*), (60). These viruses, which replicate in fish cells (BF-2), share characteristics of infectious pancreatic necrosis virus (IPNV). Two isolates from *Tellina tenuis* and one from *Ostrea edulis* proved to be antigenically distinct from the other mollusc IPNV isolates and from piscine IPN viruses (serogroup I). Thus, they represent a new IPNV serogroup (serogroup II). Infection experiments showed that some of the the IPN viruses from mussels were pathogenic to bivalve molluscs and fish (61).

Reoviridae

Reovirus infection of hatchery-grown, juvenile American oysters (*Crassostrea virginica*) was reported (62). The isolated virus, 13p2, replicated in fish cell cultures (BF-2) and was shown not to be pathogenic to oysters. However, the virus induced mortalities in juvenile bluegills (*Lepomis macrochirus*). Oysters are apparently not the natural hosts of the virus and the animals might have taken up the agent by filtration feeding.

Picornaviridae

A picornavirus-like agent was discovered in granulocytes of the bay mussel (*Mytilus edulis*). Affected animals showed granulacytomas of varying sizes in the vesicular connective tissue of digestive diverticula and mantle (63).

Retroviridae

B-type retrovirus-like particles have been isolated from soft shell clams (*Mya arenaria*) associated with hematopoietic neoplasm (64). Evidence for the involvement of the retrovirus-like agent in disease transmission is based on electron microscopic results. However, healthy clams infected with the isolated virus developed proliferative changes in hematopoietic tissue.

Bioaccumulation of human enteroviruses by molluscs. The accumulation of human enteroviruses in different shellfish species is well documented (65). Shellfish contaminated with untreated sewage or reared in polluted water are considered to be vectors and reservoirs for poliovirus, coxsackievirus, hepatitis A virus, and other pathogenic agents linked to disease outbreaks in humans.

Shellfish feed by filtering waterborne microscopic organisms at a rate of 4–20 l/hour. In addition to the food, viruses, bacteria, and other environmental particles are accumulated by the animals. A substantial number of viruses can be concentrated by the molluscs within 12–24 hours. The viruses can persist in the animals for long periods of time provided there is a sufficient amount of contaminants in the water. Concentrated viruses can be harbored by mussels, oysters, and clams until consumption. Raw, partially cooked, or steamed bivalve molluscs play a very important role in the epidemiology of enterovirus diseases. For example, severe outbreaks of hepatitis A virus disease occurred in 1976 in Australia, in 1980 in the Philippines, and in 1984 in Singapore, due to contaminated shellfish consumption (65). Approximately 300,000 people in Shanghai recently showed evidence of hepatitis A infection after consuming clams (66).

The use of polluted water in mariculture and in limniculture as well as the integrated form of aquaculture with humans and domestic animals in close environmental proximity, runs the risk of pathogen transfer. The ponds, which are fertilized by excreta from humans and farm animals, show a high level of occurrence of enteritis, diarrhoea, and hepatitis; which are acquired by eating contaminated molluscs.

VIRUSES OF CRUSTACEA

Worldwide, crustacean culture systems have suffered from increased losses due to their exposure to a certain number of infectious agents. About 25 years ago, viruses of arthropods were known only from terrestrial insects. Today, more than 30 viruses, or virus-like agents, are known and occur in several crustacean species (67–69). The etiological role of many of the viruses detected in crustaceans is not well understood, but some were found to be highly virulent.

The penaeid viruses, in particular, have caused widespread epizootics and heavy losses in shrimp and prawn aquaculture. Massive mortalities of penaeid larvae, postlarvae, and juvenile stages due to baculovirus infections have been frequently recognized in almost all of the shrimp and prawn farming countries, especially in the Asian and Indo-Pacific regions. In addition to the most virulent viruses, such as the baculoviruses (Baculovirus penaei, BP; Monodon baculovirus, MBV; mid-gut gland necrosis virus, BMNV) and the parvoviruses (hypodermal hemopoietic necrosis virus, IHHNV; hepatopancreatic virus, HPV), herpes-, picorna-, reo-, birna-, rhabdo-, bunyavirus- and togavirus-like agents were described in crustacean species (Table 4).

Herpesviridae

Herpes-like viruses (HLV) infecting hemocytes, hemopoietic tissue, epidermal cells, connective tissue, bladders, antenneal glands, and labyrinthal

Table 4. Viruses in crustacea

Herpesviridae	
Herpes-like virus (HLV)	*Callinectus sapidus, Paralithodes platypus, Rhithropanopeus harrisii*
Baculoviridae	
Baculovirus penaei (BP)	*Penaeus aztecus, P. duorarum, P. marginatus, P. setiferus, P. stylirostris, P. vannamei*
Monodon baculovirus (MBV)	*Penaeus monodon, P.esculentus, P. kerathurus, P. merguiensis, P. penicillatus, P. plebejus, P. semisulcatus, P. vannamei*
Mid-gut gland necrosis virus (BMNV)	*Penaeus japonicus*
Baculovirus A	*Callinectes sapidus*
Baculovirus B	*Carcinus maenas*
Parvoviridae	
Infectious hypodermal and hema-topoietic necrosis virus (IHHNV)	*Penaeus monodon, P. stylirostris, P. vannamei*
PC 84 virus	*Carcinus mediterraneus*
Hepatopancreatic virus (HPV)	*Penaeus merguiensis, P. monodon, P. orientalis, P. semisucatus*
Lymhoidal parvo-like virus (LPV)	*Panaeus monodon, P. merguiensis, P. esculentus*
Picornaviridae	
Chesapeak Bay virus (CBV)	*Callinectes sapidus*
Reoviridae	
Paralysis virus	*Penaeus japonicus, P. monodon*
Gill virus, RC 84 virus, W2-virus	*Callinectes sapidus, Carcinus mediterraneus*
Reo-like virus (RLV)	*Carcinus maenas*
Birnaviridae	
Infectious pancreatic necrosis virus	*Penaeus japonicus*
Rhabdoviridae	
Y-organ rhabdovirus	*Carcinus maenas, C. mediterraneus*
Rhabdoviruses A and B	*Callinectes sapidus*
Enveloped helical virus (EHV)	*Callinectes sapidus*
Bunyaviridae	
Crab hemocytopenic virus (CHV)	*Carcinus maenas*

epithelium of crabs have been reported (70-72). Infected marine crabs (*Callinectes sapidus, Pralithodes platypus, Rhithropanopeus harrisii*) became inactive and refused food before death. The herpesviruses of blue crab and blue king crab appear to be highly pathogenic to their hosts.

Baculoviridae

Baculoviruses are very host specific and cause serious epizootics associated with high mortality rates in penaeid aquaculture. Larval, postlarval, and juvenile stages of shrimp and prawn are usually the victims. The viruses infect the nuclei of hepatopancreatic epithelial and hemopoietic cells mainly leading to nuclear hypertrophy, nucleolar degeneration, and destruction of the cells (73-77). Among the several crustacean baculoviruses described, there are two important pathogens affecting the Asian shrimp industry: (a) the occluded Monodon baculovirus (MBV) infecting *Penaeus monodon, P. esculentus, P. kerathurus, P. merguiensis, P. penicillatus, P. plebejus, P. semisulcatus, P. vannamei*; and (b) the nonoccluded mid-gut gland necrosis virus (BMNV), a major pathogen of *Penaeus japonicus*.

Parvoviridae

Parvovirus-like agents have been detected in shrimp, prawn, and crabs (68,78-80). The infectious hypodermal and hematopoietic necrosis (IHHN) of penaeid shrimp caused by the IHHN virus is well known. The virus was infectious to all of the species of penaeid shrimp tested with *Penaeus stylirostris* being the most susceptible host. The acute phase of infection with IHHN virus is characterized by high mortality rates of larvae. The virus attacks several ectodermal and mesodermal tissue. Cellular necrosis, nuclear hypertrophy, karyorrhexis, pyknosis, and Cowdry-Type-A intranuclear inclusions were detected frequently. IHHNV, first described in imported penaeid shrimps in Hawaii (81), is now recognized world wide wherever penaeid shrimps are cultured.

In addition, parvoviruses have been detected in *Carcinus mediterranus* (PC 84) and in several penaeid species (e.g. hepatopancreatic parvo-like virus (HPV), lymphoidal parvo-like virus (LPV)), (78,80–82).

Picornaviridae

A picornavirus-like agent (Chesapeake Bay Virus, CBV) was detected in the hemopoietic tissue, hemocytes, neurosecretory cells, epidermis, gills, and gut of of the blue crab (*Callinectes sapidus*). After CBV infection, the animals behaved abnormally, resulting in disrupted molt patterns and death (83).

Reoviridae

Reovirus-like agents have been detected in the epicardial connective tissue, hemopoietic tissue, gill tissue, neuroglia, hepatopancreas, and hemocytes of several crabs (*Callinectes sapidus, Carcinus mediterraneus, Carcinus maenas*) and shrimp (*Penaeus japonicus, P. monodon*) associated with paralysis, gill necrosis, darkening of the exoskeleton, and mortalities (84–89). However, the pathogenicity of most of the agents is unknown.

Birnaviridae

A birnavirus-like agent was isolated from the epizootic deaths of laboratory-bred Kuruma shrimp (*Penaeus japonicus*), (28). The virus, when replicated in fish cells (RTG-2 cells, PG-cells) at 15 °C showed an antigenic relationship to the fish pathogenic infectious pancreatic necrosis virus (IPNV). However, the impact of the isolated virus to shrimp is unknown.

Halder and Ahne (90) demonstrated the freshwater crayfish *Astacus astacus* as a vector for the fish-pathogenic IPNV strain Sp. The virus was taken up from contaminated food and water by the crayfish. The agent multiplied in several tissues, was present in hemocytes, and was excreted for up to 12 months into the water by the crayfish. This excretion, in turn, infected rainbow trout fingerlings.

Rhabdoviridae

Several rhabdovirus-like agents were detected in marine crabs. The Y-organ rhabdovirus was found in the Y-organ of *Carcinus* species (91). The rhabdovirus-like A agent (RhVA) was detected in glial cells of nerves, blood vessel endothelia, hemopoietic tissue, and in hemocytes of blue crab (92). The rhabdovirus-like B agent (RhVB) has been found in madibular organs of blue crab (*Callinectes sapidus*) (93).

Furthermore, an enveloped helical virus (EHV) was detected in the tissues and hemocytes of blue crab (94). The virus was first described as a paramyxovirus but was later assigned to the *Rhabdoviridae* (67). Only RhVA has been identified as a pathogen, the etiological roles of the other rhabdovirus-like agents are not known.

Bunyaviridae

The crab hemocytopenic virus (CHV), a bunyavirus-like agent, was detected in the shore crab (*Carcinus maenas*). The virus was responsible for an in vitro clotting effect of hemocytes. Infected animals showed a marked reduction of circulating hemocytes followed by death (95,96). The impact of the described bunyavirus-like agents on crabs in nature is unknown.

Togaviridae

Certain cells of lymphoid organs of cultured penaeid shrimps (*Panaeus vannamei*) contained in the cytoplasm icosahedral enveloped particles of 52–54 nm in diameter. The virus-like particles were found to share characteristics with togaviruses. At present, nothing is known about the pathogenicity of the so called *lymhoid organ vaculization virus* (LOVV) (97).

CONCLUSIONS

At present, aquaculture shows a rapid expansion. However, infectious agents such as viruses were frequently recognized in farmed molluscs, crustaceans, and fish. Viral infections are one of the most limiting factors of intensive aquaculture leading to disease risks and losses in fresh water aquaculture and marine farming. The problems of diseases increasingly arise, especially in Asian and Pacific regions, due to transfer of infectious agents. In addition, diseases arise due to inadequate farming conditions which often break down the natural barriers between host and the pathogens. However, most of the losses by infectious agents could be prevented by health inspections, adequate environments, and sound management practices (98). Effective control measures of viral diseases in aquaculture are sparse, but health inspection, hygiene, avoidance of pathogens, the improvement of environments, and fortifying the host resistance are practicle methods to minimize hazards of infectious diseases in farmed aquatic animals.

Acknowledgments—The skillfull assistance of Sandra Eßbauer is greatly appreciated.

REFERENCES

1. Francki, R.I.B., Fauquet, C.M., Knudson, D.L., Brown, F. (1991). Classification and nomenclature of viruses. Arch. Virol. Suppl. 2, Springer Verlag, Wien, New York.
2. Ahne, W., Bohl, M. (1990). Developments in aquaculture. Pro Veterinario 10: 2.
3. Sano, M., Fukuda, H., Sano, T. (1990). Isolation and characterization of a new herpesvirus from eel. In: Perkins, T.O., Cheng, T.C. (eds.) Pathology in marine sciences. Academic Press, New York, pp. 15-31.
4. Plumb, J.A. (1989). Channel catfish herpesvirus. In: Ahne, W., Kurstak, E. (eds.) Viruses of lower vertebrates. Springer Verlag, Berlin, Heidelberg, pp. 198-216.
5. Miyazaki, T., Fujiwara, K., Kobara, J. Matsumoto, N., Abe, M., Nagano, T. (1989). Histopathology associated with two viral diseases of larval and juvenile fish: epidermal necrosis of the Japanese flounder, *Paralichthys olivaceus*, and epithel necrosis of black sea bream, *Acanthopagrus schlegeli*. J. Aquat. Anim. Health 1: 85-93.
6. Iida, Y., Nakai, T., Sorimachi, M., Masumura, K. (1991). Histopathology of a herpesvirus infection in larvae of Japanese flounder, *Paralichthys olivaceus*. Dis. aquat. Org. 10: 59-63.
7. Sano, T., Fukuda, H., Furukawa, M., Hosoya, H., Moriya, Y. (1985). A herpesvirus isolated from carp papilloma in Japan. In: Ellis, A.E. (ed.) Fish and shellfish pathology, Academic Press, London, pp. 307-311.
8. Sano, T. (1976). Viral diseases of cultured fish in Japan. Fish Pathol. 10: 221-226.
9. Kimura, T., Yoshimizu, M., Tanaka, M. (1981). Studies on a new virus (OMV) from *Oncorhychus masou*. Fish Pathol. 15: 149-153.
10. Kimura, T., Yoshimizu, M., Tanaka, M., Sannohe, H. (1989). Studies on a new virus (OMV) from *Oncorhychus masou*. Fish Pathol. 15: 43-147.
11. Sano, T., Fukuda, H., Okamoto, N., Kaneko, F. (1983). Yamame tumor virus: lethality and oncogenicity. Bull. Jap. Soc. Sci. Fish. 49: 1159-1163.
12. Sano, T. (1988). Characterization, pathogenicity and oncogenicity of herpesvirus in fish. Abstract from Intern. Fish Health Conf., Vancouver, Canada (pp. 157).
13. Hedrick, R.P., McDowell, T., Eaton, W.D., Kimura, T., Sano, T. (1987). Serological relationships of five herpesviruses isolated from salmonid fish. J. Appl. Ichthyol. 3: 87-92.
14. Ahne, W. (1988). Viral infections of aquatic organisms. J. Vet. Med. B 35: 493-503.
15. Yoshimizu, M., Kimura, T. (1990). Viral infections of cultured fish in Japan. Proceedings from Sec. Asian Fish. Forum, Asian Fish. Soc., Manila, pp. 959-962.
16. Hedrick, R.P., McDowell, T.S., Ahne, W., Torchy, C., de Kinkelin, P. (1992). Properties of three iridovirus-like agents associated with systemic infections of fish. Dis. aquat. Org. 13: 203-209.
17. Langdon, J.S., Humphrey, J.D., Williams, L.M., Hyatt, A.D., Westbury, H.A. (1986). First virus isolation from Australian fish: an iridovirus-like pathogen from redfin perch, *Perca fluviatilis* L. J. Fish Dis. 9: 263-268.
18. Langdon, J.S. (1989). Experimental transmission and pathogenicity of epizootic hematopoietic necrosis virus (EHNV) in redfin perch, *Perca fluviatilis* L., in Australia. J. Fish Dis. 12: 295-310.
19. Ahne, W., Schlotfeldt, H.J., Thomsen I. (1989). Fish viruses: Isolation of an icosahedral cytoplasmic deoxyribovirus from sheatfish (*Silurus glanis*). J. Vet. Med. 36: 333-336.
20. Pozet, F., Morand, M., Moussa, A., Torhy, C., de Kinkelin, P. (1992). Isolation and preliminary characterization of a pathogenic icosahedral deoxyribovirus from the catfish (*Ictalurus melas*). Dis aquat. Org. 14: 35-42.
21. Sorimachi, M. (1984). Pathogenicity of ICD virus isolated from Japanese eel. Bull. Natl. Inst. Aquacult. 6: 71-75.
22. Armstrong, R.D., Ferguson, H.W. (1989). Systemic viral disease of the chromid cichlid *Etroplus maculatus*. Dis. aquat. Org. 7: 155-157.
23. Chen, Y., Jiang, Y. (1984). Morphological and physico-chemical characterization of the hemorrhagic virus of grass carp. Kexue-Tongboa (China) 29: 832-835.
24. Ke, L., Fang, Q., Cai, Y. (1990). Characteristics of a novel isolate of grass carp hemorrhagic virus. Acta Hydrobiol. Sinica 14: 155-159.
25. Hsu, Y.L., Chen, B.S., Wu, J.L. (1989). Characteristics of a new reo-like virus isolated from landlocked salmon (*Oncorhynchus Masou* Brevoort) Fish Pathol. 24: 37-45.
26. Jiang, Y., Ahne, W., Li, Y., Ogawa, M. (1991). Isolation of an aquareovirus from common carp (*Cyprinus carpio*) in the People's Republic of China. Proc. Sec. Intern. Symp. Viruses of Lower Vertebrates, Oregon State University, Corvallis, OR. pp. 287-292.
27. Hill, B.J. (1982). Infectious pancreatic necrosis virus and its virulence. In: Roberts, R.J. (ed.) Microbial diseases of fish. Spec. Publ. Soc. Gen. Microbiol. Academic Press, New York, pp. 91-114.
28. Bovo, G., Ceschia, G., Giorgetti, G., Vanelli, M. (1984). Isolation of an IPN-like virus from adult Kumura shrimp (*Penaeus japonicus*). Bull. Eur. Ass. Fish Pathol. 4: 21.
29. Comps, M., Menu, B., Breuil, G., Bonami, J.R. (1990). Virus isolation from mass cultivated rotifers, *Brochionus plicatilis*. Bull. Eur. Ass. Fish. Pathol. 10: 37-38.
30. Lipipun, V., Caswell-Reno, P., Hsu, Y.L., Wu, J.L., Tung, M.C., Reno, P.W., Wattanavijarn, W., Nicholson, B. (1989). Antigenic analysis of Asian aquatic birnavirus isolates using monoclonal antibodies. Fish Pathol. 24: 155-160.
31. Okamoto, N., Sano, T., Hedrick, R.P., Fryer, J.L. (1983). Antigenic relationship of selected strains of infectious pancreatic necrosis virus and Europenan eel virus. J. Fish Dis. 6: 19-25.
32. Hedrick, R.P., Eaton, W.D., Fryer, J.L., Hah, Y.C., Park, J.W., Hong, S.W. (1985). Biochemical and serological properties of birnaviruses isolated from fish in Korea. Fish Pathol. 20: 463-468.
33. Jiang, Y., Li, Z. (1987). Isolation of IPN virus from imported rainbow trout (*Salmo gairdneri*). J. Appl. Ichthyol. 3: 191-192.
34. Nishimura, T., Fukuda, H., Yamazaki, H., Sano, T. (1981). Concentration and purification of eel virus, EVE. Fish Pathol. 16: 75-83.
35. Sano, T., Okamoto, N., Nishimura, T. (1981). A new

viral epizootic of *Anguilla japonica*. J. Fish Dis. 4: 127-139.
36. Lipipun, V., Caswell-Reno, P., Reno, P., Nicholson, B. (1988). Enzyme immunoassay utilizing monoclonal antibodies for identification of European eel virus (EEV): an aquatic birnavirus. In: Yentsch, C., Mague, F., Horan, Ph. (eds.) Immunological approaches to coastal, eustarine and oceanographic questions, Springer Verlag, Heidelberg, pp. 312-317.
37. Hedrick, R.P., Fryer, J.L., Chen, S.N., Kou, G.H. (1983). Characteristics of four birnaviruses isolated from fish in Taiwan. Fish Pathol. 18: 91-97.
38. Sano, T., Nishimura, T., Okamoto, N., Fukuda, H. (1977). Studies on viral diseases of Japanese fish VII: a rhabdovirus isolated from European eel (*Anguilla anguilla*). Fish Pathol. 43: 491-495.
39. Hill, B.J., Williams, R.F., Smale, C.J., Underwood, B.O., Brown, F. (1980). Physical and serological characterization of two rhabdoviruses isolated from eels. Intervirol. 14: 208-212.
40. Niu, L., Zhao, Z. (1988). The epidemiological IHN and IPN of rainbow trout in Northeast China. J. Fish. China, 12: 327-332.
41. de Kinkelin, P., Galimard, D., Bootsma, R. (1973). Isolation and identification of the causative agent of "Red Diseases" of pike (*Esox lucius* L. 1766). Nature. 241: 465-467.
42. Ahne, W. (1975). A rhabdovirus isolated from grass carp (*Ctenopharyngodon idella* Val.). Arch. Virol. 48: 181-185.
43. Kimura, T., Yoshimizu, M., Gorie, S. (1986). A new rhabdovirus isolated in Japan from cultured hirame (Japanese flounder) *Paralichthys olivaceus* and ayu *Plecoglossus altivelis*. Dis. aquat. Org. 1: 209-217.
44. Kimura, T., Yoshimizu, M., Oseko, N., Nishizawa, T. (1989). *Rhabdovirus olivaceus* (Hirame Rhabdovirus) In: Ahne, W., Kurstak, E. (eds.) Viruses of lower vertebrates. Springer Verlag, Heidelberg, pp. 388-395.
45. Frerichs, G.N., Millar, S.D., Roberts, R.J. (1986). Ulcerative rhabdovirus in fish in South-East Asia. Nature 322: 216.
46. Wattanavijarn, W., Tangtronpiros, J., Wattanadorn, K. (1986). Viruses of ulcerative diseased fish in Thailand, Burma and Laos. Abstract from First Internt. Conf. Impact Viral Dis. Develop. Countries, Bangkok, pp. 121.
47. Ahne, W., Jorgensen, P.E.V., Olesen, N.J., Wattanavijarn, W. (1988). Serological examination of a rhabdovirus isolated from snakehead (*Ophicephalus striatus*) in Thailand with ulcerative syndrome. J. Appl. Ichthyol. 4: 194-196.
48. Frerichs, G.N., Hill, B.J., Way, K. (1989). Ulcerative rhabdovirus: cell line susceptibility and serological comparison with other fish rhabdoviruses. J. Fish Dis. 12: 151-156.
49. Frerichs, G.N., Millar, S.D., Alexander, M. (1989). Rhabdovirus infection of ulcerated fish in South East Asia. In: Ahne, W., and Kurstak, E. (eds.) Viruses of lower vertebrates, Springer Verlag, Heidelberg, pp. 396-410.
50. Sano, T., Yamaki, T., Fukuda, H. (1988). A novel carp coronavirus: characterization and pathogenicity. Abstract from Intern. Fish Health Conf., Vancouver, Canada (pp. 160).
51. Elston, R. (1984). Prevention and management of infectious diseases in intensive mollusc husbandry. J. Word Maricult. Soc. 15: 284-300.
52. Farley, C.A., Banfield, W.G., Kasnic, G., Jr., Forster, W.S. (1972). Oyster herpes-type virus. Science 178: 759-760.
53. Alderman, D.J. (1980). Shellfish diseases: past, present, and future. Proc. 11th Ann. Conf. Shellfish Assoc. Great Britain, pp. 10-40.
54. Hine, P.M., Wesney, B., Hay, B.E. (1992). Herpesviruses associated with mortalities among hatchery-reared larval Pacific oysters, *Crassostrea gigas*. Dis. aquat. Org. 12: 135-142.
55. Nicolas, J.L., Comps, M., Cochennec, N. (1992). Herpes-like virus infecting Pacific oyster larvae, *Crassostrea gigas*. Bull. Eur. Ass. Fish Pathol. 12: 11-13.
56. Comps, M. (1988). Epizootic diseases of oysters associated with viral infections. In: Fisher, W.S. (ed.) Disease process in marine bivalve molluscs, Am. Fish. Soc. Spec. Publ. 18, pp. 23-37.
57. Elston, R. (1979). Virus-like particles associated with lesions in larval Pacific oysters (*Crassostrea gigas*). J. Invertebr. Pathol. 33: 71-74.
58. Farley, C.A. (1976). Ultrastructural observations on epizootic neoplasia and lytic virus infection in bivalve molluscs. Prog. Exp. Tumor Res. 20: 283-294.
59. Zhang, Z., Ding, S., Wang, J., Qui, B., Pei, M. (1986). Studies on the mussel *Hyriopsis cumingii* plaque II: a new arenavirus is the pathogen of *Hyriopsis cumingii* plaque. Acta Microbiol. Sinica 26: 308-312.
60. Hill, B.J. (1976). Molluscan viruses: their occurrence, culture and relationship. Proc. First. Intern. Colloq. Invertebr. Pathol., Queens University, Kingston, Ont. pp. 25-29.
61. Hill, B.J., Alderman, D.J. (1979). Observations on the experimental infection of *Ostrea edulis* with two molluscan viruses. Haliotis 8: 297-299.
62. Meyers, T.R. (1979). A reo-like virus isolated from juvenile American oysters (*Crassostrea virginica*). J. gen. Virol. 43: 203-212.
63. Rasmussen, L.P.D. (1986): Virus-associated granulocytomas in the marine mussels *Mytilus edulis*, from three sites in Denmark. J. Invertebr. Pathol. 48: 117-123.
64. Oprandy, J.J., Chang, P.W., Pronovost, A.D., Cooper, K.R., Brown, R.S., Yates, R.S. (1981). Isolation of a viral agent causing hematopoietic neoplasia in the soft shell clam, *Mya arenaria*. J. Invertebr. Pathol. 38: 45-52.
65. Rao, V.C., Melnick, J.L. (1986). Environmental virology. Am. Soc. Microbiol. 13: 1-88.
66. Halliday, M.L., Kang, L.Y., Zouh, T.K., Hu, M.D., Pan, Q.C., Fu, T.Y., Huang, Y.S., Hu, S.L. (1991). An epidemic of hepatitis A attributable to the ingestion of raw clams in Shanghai, China. J. Infect. Dis. 164: 853-859.
67. Johnson, P.T. (1984). Viral diseases of marine invertebrates. Helgol. Meeresunters. 37: 65-98.
68. Lightner, D.V. (1988). Diseases of cultured penaeid shrimp and prawns. In: Sindermann, C.J., Lightner, D.V. (eds.) Disease, diagnosis and control in North American aquaculture. Elsevier, New York, pp. 8-127.
69. Brock, J.A., Lightner, D.V. (1990). Diseases of crustacea. In: Kinne, O. (ed.) Diseases of marine animals.

Biologische Anstalt Helgoland, Hamburg, Germany, pp. 245-423.
70. Johnson, P.T. (1976). A herpes-like virus from the blue crab, *Callinectes sapidus*. J. Invertebr. Pathol. 27: 419-420.
71. Payen, G.G., Bonami, J.R. (1979). Mise en evidence de particules d'allure virale associees aux noyaux des cellules mesodermiques de la zone germinative testiculaire du crabe *Rhithropanopeus harrisii* (Gould). Rev. Trav. Inst. Pech. Marit. 43: 361-365.
72. Sparks, A.K., Morado, J.F. (1986). A herpes-like virus disease in the blue king crab *Paralithodes platypus*. Dis. aquat. Org. 1: 115-122.
73. Bazin, F., Monsarrat, P., Bonami, J.R., Croizier, G., Meynadier, G., Quiot, J.M., Vago, C. (1974). Particules virales de type baculovirus observees chez le crabe *Carcinus maenas*. Rev. Trav. Inst. Pech. Marit. 38: 205-208.
74. Couch, J.A. (1974). Free and occluded virus, similar to baculovirus, in hepatopancreas of pink shrimp. Nature 247: 229-231.
75. Johnson, P.T. (1976). A baculovirus from the blue crab, *Callinectes sapidus*. Proc. Int. Colloq. Invertebr. Pathol. Queens University, Kingston, Ont. pp. 24.
76. Papparlardo, R., Bonami, J.R. (1979). Infection des crustaces marins due a un virus de type nouveau apparente aux Baculovirus. C. R. Hebd. Seanc. Acad. Sci. Paris, D 288: 535-537.
77. Sano, T., Nishimura, T., Oguma, K., Momoyama, K., Takeno, N. (1981). Baculovirus infection of cultured Kuruma shrimp, *Penaeus japonicus*, in Japan. Fish Pathol. 15: 185-191.
78. Lightner, D.V., Redman, R.M. (1985). A parvo-like virus disease of penaeid shrimp. J. Invertebr. Pathol. 45: 47-57.
79. Mari, J., Bonami, J.R. (1988). PC 84: a parvo-like virus from the crab *Carcinus mediterraneus*, pathologic aspects, ultrastructure of the agent and first biochemical characterization. J. Invertebr. Pathol. 51: 145-156.
80. Owens, L., de Beer, S., Smith, J. (1991). Lymphoidal parvovirus-like particles in Australian penaeid prawns. Dis. aquat Org. 11: 129-134.
81. Lightner, D.V., Redman, R.M., Bell, T.A., Brok, J.A. (1983). Detection of IHHN virus in *Penaeus stylirostris* and P. vannamei imported into Hawaii. J. Wildl. Maricult. Soc. 14: 212-155.
82. Roubal, F.R., Paynter, J.L., Lester, R.J.G. (1989). Electron microscopic observation of hepatopancreatic parvo-like virus (HPV) in the penaeid prawn, *Penaeus merguiensis* de Man, from Australia. J. Fish Dis. 12: 199-201.
83. Johnson, P.T. (1978). Viral diseases of the blue crab, *Callinectes sapidus*. Mar. Fish Rev. 40: 13-15.
84. Vago, C. (1966). A virus disease in Crustacea, Nature 209: 1290.
85. Bonami, J.R. (1973). Recherche sur la paralysie virale du Crustace Decapode, *Macropipus depurator* L. Rev. Trav. Inst. Pech. Marit. 37: 387-389.
86. Johnson, P.T., Bodammer, J.E. (1975). A disease of the blue crab, *Callinectes sapidus*, of possible viral etiology. J. Invertebr. Pathol. 26: 141-143.
87. Mari, J., Bonami, J.R. (1987). A reolike virus of the Mediterraneum shore crab *Carcinus mediterranus*. Dis. aquat. Org. 3: 107-112.
88. Tsing, A., Bonami, J.R. (1987). A new viral disease of the tiger shrimp, *Penaeus japonicus*. J. Fish Dis. 10: 139-141.
89. Nash, M.B., Nash, G., Anderson, I.G., Shariff, M. (1988). A reo-like virus observed in the tiger prawn, *Penaeus monodon* Fabr., from Malaysia. J. Fish Dis. 11: 531-535.
90. Halder, M., Ahne, W. (1988). Freshwater crayfish *Astacus astacus* – a vector for infectious pancreatic necrosis virus (IPNV). Dis. aquat. Org. 4: 205-209.
91. Chassard-Bouchaud, C., Hubert, M. (1975). Sur l'existence de vesicules de reticulum endoplasmique lisse dans l'organe Y de *Carcinus maenas* L. (Crustace, Decapode). C. R. Hebd. Seanc. Acad. Sci. Paris D 281: 707-709.
92. Jahromi, S.S. (1977). Occurrence of rhabdovirus-like particles in the blue crab, *Callinectes sapidus*. J. Gen. Virol. 36: 485-493.
93. Yudin, A.I., Clark, W.H. (1979). A description of rhabdovirus-like particles in the mandibular gland of the blue crab (*Callinectes sapidus*). J. Invertebr. Pathol. 33: 133-147.
94. Johnson, P.T., Farley, C.A. (1980). A new enveloped helical virus from the blue crab, *Callinectes sapidus*. J. Invertebr. Pathol. 35: 90-92.
95. Bang, F.B. (1971). Transmissible disease, probably viral in origin, affecting the amebocytes of the European shore crab, *Carcinus maenas*. Infect. Immun. 3: 617-623.
96. Bang, F.B. (1974). Pathogenesis and autointerferences in a virus disease of crabs. Infect. Immun. 9: 1057-1061.
97. Bonami, J.R., Lightner, D.V., Redman, R.M., Poulos, B.T. (1992). Partial characterization of a togavirus (LOVV) associated with histopathological changes of the lymphoid organ of penaeid shrimps. Dis. aquat. Org. 14: 145-152.
98. Ahne, W., Winton, J.R., Kimura, T. (1989). Prevention of infectious diseases in aquaculture. J. Vet. Med. 36: 561-567.