Etiology, Pathology and Management of Major Fish Diseases: A Comprehensive Review for Sustainable Aquaculture

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Abstract

Fish diseases caused by viral, bacterial, fungal, and parasitic agents remain a primary constraint to global aquaculture productivity. This review synthesizes current knowledge on the etiological agents, pathological manifestations, epidemiological determinants, and evidence-based management strategies for major infectious fish diseases. The 'disease triangle' framework comprising host susceptibility, pathogen virulence, and environmental perturbation is employed to analyze disease dynamics. Environmental stressors, particularly temperature fluctuations, deteriorating water quality, and intensive stocking, are identified as critical predisposing factors that compromise host immunity and facilitate pathogen establishment. A systematic categorization of viral (VHS, IHN, SVC), bacterial (Columnaris, MAS, Edwardsiellosis, Furunculosis, BKD, EUS), fungal (Saprolegniasis, Branchiomycosis), and parasitic diseases (Myxosporidiosis, Dactylogyrosis, Argulosis) is presented along with their clinical profiles and recommended chemotherapeutic and prophylactic regimens. The review underscores the urgent need for integrated health management protocols and advances in immunoprophylaxis and environmentally sustainable biocontrol strategies.

Keywords: Aquaculture pathology, Ichthyopathology, Disease triangle, Chemotherapy, Immunoprophylaxis, Integrated fish health management

1. Introduction

Global aquaculture has experienced exponential growth over recent decades, now contributing over 50% of fish for human consumption (Little et al., 2016). Despite this remarkable expansion, infectious disease outbreaks remain the most significant biological and economic constraint to sustainable fish production. Mortality events attributable to pathogenic organisms result in annual losses estimated in the billions of US dollars, severely undermining food security objectives in both developed and developing economies. Disease pathogenesis in fish is fundamentally multifactorial, governed by the complex interactions captured within the classical 'disease triangle': the vertebrate host, the etiological agent, and the ambient environment (Scholthof, 2007). Under conditions of environmental stress - including rapid temperature shifts, dissolved oxygen depletion, hypercapnia, elevated unionised ammonia, and excessive stocking density host immune competence is compromised, creating conditions permissive to opportunistic infection and frank pathogen invasion (Cascarano et al., 2021). Mishra et al. (2017) documented that the majority of disease outbreaks in Indian freshwater aquaculture are directly precipitated by deterioration of water quality parameters, a finding corroborated by extensive field observations across tropical and subtropical production systems.

This article systematically examines the principal infectious diseases affecting cultured fish, with emphasis on their etiological basis, pathological manifestations, and contemporary management approaches. Understanding these disease processes at a mechanistic level is essential for the development of rational, evidence-based intervention strategies that minimize reliance on broad-spectrum chemotherapy (Noga, 2010; Shrivastava et al., 2025).

2. Predisposing Environmental and Management Factors

The onset of infectious disease in fish populations rarely follows simple host-pathogen dyad dynamics. Environmental perturbations function as the primary gateway through which pathogens gain advantage over host defense mechanisms. Svobodova et al. (1993) identified thermal fluctuation as the single most important environmental trigger, with thermal stress inducing cortisol-mediated immunosuppression and rendering fish susceptible to a broad spectrum of pathogens.

Water quality parameters of critical significance include dissolved oxygen (optimal range 5–8 mg/L), pH (6.5–8.5), un-ionized ammonia (<0.02 mg/L), and carbon dioxide (<10 mg/L). Turbidity elevation associated with organic loading reduces the phagocytic efficiency of immune effector cells and promotes proliferation of facultative pathogens. Anthropogenic inputs - agricultural runoff, industrial effluents, and municipal wastewater introduce xenobiotic compounds that synergistically suppress host immunity while simultaneously elevating pathogen burdens in the water column. High stocking densities exacerbate these stressors by increasing waste metabolite accumulation, physical injury through conspecific aggression, and facilitating horizontal pathogen transmission (Cascarano et al., 2021; Carlino-Costa & Belo, 2025).

3. Major Infectious Disease Groups: Etiology and Clinical Profiles

3.1 Viral Diseases

Viral infections in fish are particularly challenging due to the absence of effective chemotherapeutic agents and the limited availability of licensed vaccines for most pathogens. Table 1 summarizes the major viral diseases, their etiological agents, and characteristic clinical presentations.

Table 1 Major viral diseases of fish: Etiology and clinical signs

Disease	Causative Agent	Key Symptoms	Reference
Viral Haemorrhagic Septicaemia (VHS)	*VHSV (Novirhabdovirus)*	Exophthalmia, haemorrhagic skin discolouration, abdominal distension, lethargy; high mortality in salmonids	Meyers & Winton, 1995
Infectious Haematopoietic Necrosis (IHN)	*IHNV (Rhabdoviridae)*	Abdominal distension, exophthalmia, skin darkening, fecal casts, anaemia; acute mortalities in salmonid fry	LaPatra, 1994
Spring Viraemia of Carp (SVC)	*SVCV (Rhabdoviridae: Vesiculovirus)*	Haemorrhagic ascites, pale gills, exophthalmia, petechiae; principally affects cyprinids in spring	Waltzek et al., 2005

Viral haemorrhagic septicaemia virus (VHSV) represents one of the most economically significant fish pathogens globally, affecting over 80 species across Eurasia and North America. The virus causes severe systemic haemorrhagic disease in rainbow trout and numerous marine species, with mortality rates approaching 100% in susceptible populations under acute infection. In the absence of licensed therapeutics, management relies exclusively on stringent biosecurity protocols, regular population surveillance, and chlorine-based disinfection of water systems (Meyers & Winton, 1995). IHN similarly lacks approved pharmacological interventions, with disease control dependent upon isolation of infected stocks, elimination of carrier fish, and implementation of epidemiological testing protocols (LaPatra, 1994). SVC, caused by a Vesiculovirus, remains notifiable to the World Organisation for Animal Health (WOAH) due to its rapid spread among cyprinid populations and associated production losses (Waltzek et al., 2005).

3.2 Bacterial Diseases

Bacterial pathogens constitute the most diverse and economically impactful group of infectious agents in aquaculture. Their capacity to exploit stressed hosts renders them particularly problematic in intensive production systems. Table 2 presents the principal bacterial diseases encountered in cultured fish.

Table 2 Principal bacterial diseases of fish: etiology, clinical signs

Disease	Causative Agent	Key Symptoms	Reference
Columnaris Disease	*Flavobacterium columnare (syn. Flexibacter columnaris)*	Greyish-white epidermal lesions; saddle-shaped dorsal ulcers; gill necrosis; 'cottonwool' appearance	Davis, 1922; Declercq et al., 2013
Motile Aeromonad Septicaemia (MAS)	*Aeromonas hydrophila, Pseudomonas fluorescens*	Haemorrhagic ascites, hepatic necrosis, exophthalmia; systemic septicaemia	JSTAGE, 2019; Austin & Austin, 2007
Edwardsiellosis	*Edwardsiella tarda*	Scale loss, skin lesions, malodorous muscle gas cavitations; necrosis of musculature	Vincent, 2012; Mohanty & Sahoo, 2007
Furunculosis	*Aeromonas salmonicida*	Haemorrhagic septicaemia; muscle boil-like lesions (furuncles); blood-stained exudate	Cain & Polinski, 2014; Bernoth & Körting, 1992
Bacterial Kidney Disease (BKD)	*Renibacterium salmoninarum*	Swollen kidney; granulomas; abdominal fluid; white viscous intestinal content	Wiens & Kaattari, 1999
Epizootic Ulcerative Syndrome (EUS)	*Aphanomyces invadans + Aeromonas spp.*	Chronic deep red ulcers; 'cauliflower' mouth deformity; skin necrosis	Kar, 2015

Columnaris disease, caused by *Flavobacterium columnare* (previously classified as *Flexibacter columnaris*), affects a wide spectrum of commercially important freshwater species and is associated with significant mortality particularly in warm-water conditions (Davis, 1922). Motile *Aeromonad* Septicaemia (MAS), primarily attributed to *Aeromonas hydrophila*, is an opportunistic infection of global prevalence, invariably associated with environmental stressors and compromised host immunity (JSTAGE, 2019). Bacterial Kidney Disease, caused by the Gram-positive *Renibacterium salmoninarum*, is among the most challenging bacterial infections in salmonid aquaculture due to its intracellular lifestyle, vertical transmission, and resistance to conventional antibiotic regimens (Wiens & Kaattari, 1999). Epizootic Ulcerative Syndrome, classified as a notifiable disease by WOAH, has caused catastrophic losses in Asian freshwater fisheries, with *Aphanomyces invadans* now established as the primary mycotic agent in a polymicrobial pathogenesis model (Kar, 2015).

3.3 Fungal and Parasitic Diseases

Fungal infections in fish are predominantly secondary conditions precipitated by prior physical trauma, nutritional deficiency, or immunosuppression. Saprolegnia spp. remain the most prevalent aquatic fungi affecting freshwater teleosts globally, causing characteristic cotton-like mycelial growths that penetrate host tissues and precipitate inflammatory responses (Robertson et al., 2009). Branchiomycosis, caused by *Branchiomyces sanguinis* and *B. demigrans*, produces necrotic gill pathology and respiratory compromise, often culminating in acute mortality (Özcan & Arserim, 2022).

Among protozoan parasites, *Ichthyobodo necator* (previously *Costia necatrix*) is a ubiquitous obligate ectoparasite responsible for costia disease, characterized by grayish-white epidermal films and haemorrhagic patches (Becker, 1977). *Myxobolus cerebralis*, the causative agent of whirling disease, invades cartilaginous tissues of salmonid juveniles, producing severe skeletal deformity and characteristic whirling locomotor disturbance (Bruno et al., 2006). Monogenean trematodes of the genera Dactylogyrus and Gyrodactylus are among the most prevalent and economically significant ectoparasites in freshwater aquaculture, causing extensive gill and skin pathology through mechanical abrasion and mucus hypersecretion (Mhaisen & Abdul-Ameer, 2019; Cojocaru, 2007). Crustacean ectoparasites, including *Argulus* spp. (fish lice) and *Lernaea* spp. (anchor worms), cause significant physical trauma, immune suppression, and predispose infested fish to secondary bacterial infections (Misganaw & Getu, 2016).

4. Integrated Disease Management Strategies

Effective fish disease management necessitates a multi-pronged integrated approach encompassing preventive, therapeutic, and prophylactic dimensions. Prophylactic pond management remains the foundational strategy: pre-stocking disinfection with quicklime (400–600 kg/ha in new ponds; 500–800 kg/ha in old ponds) and bleaching powder (50–100 kg/ha) effectively reduces environmental pathogen loads. Routine disinfection of equipment with 5–25 ppm formalin or 250 ppm $KMnO4$ prevents cross-contamination between production units (Noga, 2010).

Therapeutic intervention protocols include primary chemical treatments using potassium permanganate (2–3 ppm pond application; 100–250 ppm bath treatment for 2–3 min), copper sulphate (1–2 ppm), and sodium chloride (2–3% bath treatment). Antibiotic therapy, where pathogen susceptibility is confirmed, employs oxytetracycline (50–60 mg/100 kg fish/day for 15 days per os), erythromycin phosphate (1 mg/kg BW for BKD), and sulphonamide compounds. Parenteral antibiotic administration (streptomycin 25 mg + penicillin 20,000 IU/kg BW) is reserved for high-value broodstock exceeding 1 kg. Critical management principles include maintenance of optimal stocking densities, provision of nutritionally balanced diets, regular netting (bi-monthly), and monthly water exchange of 30 cm depth (Noga, 2010; Shrivastava et al., 2025).

5. Conclusion

Fish infectious diseases, arising from the complex interplay of pathogen virulence, host susceptibility, and environmental determinants, constitute one of the most pressing challenges confronting global aquaculture. An integrative, evidence-based approach to disease management combining rigorous environmental monitoring, prophylactic chemotherapy, nutritional optimization, and emerging immunoprophylactic technologies is essential for the long-term sustainability of intensive fish production. Future research priorities must encompass the development of efficacious vaccines, host-specific probiotics, and biological control agents that reduce dependence on broad-spectrum antibiotics, thereby mitigating the risk of antimicrobial resistance and ensuring the production of safe aquatic food products.

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