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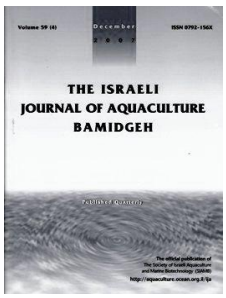

Diseases of Mariculture Finfish Species: A Review

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Abstract

Mariculture has been steadily growing over the last few decades. To satisfy the increasing demand of local and export markets for fish and to control overexploitation of marine fish species, many countries are expanding mariculture activities. Disease is one of the most limiting factors in mariculture. Intensification of mariculture favors pathogens, which increase disease outbreaks. Diseases are broadly classified into infectious and noninfectious diseases. Infectious diseases are further divided into four groups based on the nature of the pathogen: viral, bacterial, parasitic, or fungal. Noninfectious diseases are divided into neoplastic diseases, genetic and environmentally induced diseases, and nutritional deficiency diseases. This paper provides detailed information regarding prevalent diseases of maricultured finfish species.

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Introduction

Aquaculture is the world's fastest growing food production sector. A global review of marine capture fisheries reveals that 80% of the world's fish stocks for which stock assessment information is available are fully exploited and the world's maximum wild capture fisheries potential is almost exploited. Thus, a more closely controlled and precautionary approach to fisheries management is essential. In this context, mariculture is an excellent alternative for sustainable marine fish production. Mariculture is defined as the cultivation, management, and harvesting of marine organisms in their natural habitat or in specially constructed rearing units such as ponds, cages, pens, enclosures, or tanks (FAO, 2009). With stagnating global capture fishery production and an increasing population, aquaculture has the greatest potential to produce fish to meet the growing demand for safe and quality aquatic food; by 2012, over 50% of global food fish consumption will originate from aquaculture (FAO, 2009).

The total world fish production in 2008 was estimated at 142.3 million tons (FAO, 2011). Global production of food fish from aquaculture, including finfish, crustaceans, mollusks, and other aquatic animals for human consumption, reached 52.5 million tons in 2008, compared with 32.4 million tons in 2000. Freshwater aquaculture contributed 59.9% of world aquaculture production by quantity and 56.0% by value while mariculture in the sea and in ponds accounted for 32.3% by quantity and 30.7% by value. Marine aquaculture produces many high-value finfish, crustaceans, gastropods, and bivalves including oysters, mussels, clams, cockles, and scallops. In 2008, freshwater fishes dominated production with 28.8 million tons (54.7%) valued at US$40.5 billion (41.2%), followed by mollusks (13.1 million tons), crustaceans (5 million tons), diadromous fishes (3.3 million tons), marine fishes (1.8 million tons), and other aquatic animals (0.62 million tons). Among marine fishes, flatfish production increased from 26,300 tons in 2000 to 148,800 tons in 2008, the leading producers being China and Spain. The major species were turbot (*Scophthalmus maximus*), bastard halibut (*Paralichthys olivaceus*), and tongue sole (*Cynoglossus semilaevis*).

Under natural environmental conditions, coastal waters are free of obstructions. However, the placement of floating net-cages along waterways has created 'artificial islands', resulting in the congregation of diverse biological communities of vertebrate and invertebrate organisms. One could expect to find a similar congregation of bacteria, viruses, fungi, parasites, and other pathogens within this newly-created ecosystem, in addition to the naturally occurring wild aquatic organisms. Increasing intensification and lack of proper health management measures have lead to many disease problems of bacterial, viral, fungal, and parasitic origin. Further, the improper use of chemicals and antibiotics raises concerns regarding human and environmental safety (Seng et al., 2006).

The types and severity of diseases are greatly influenced by the fish species, conditions in which the animals are cultured, and husbandry management. Fish cultured in floating cages are particularly susceptible to diseases when environmental parameters such as temperature, salinity, dissolved oxygen, and suspended particles suddenly or widely fluctuate, and following rough, although often unavoidable, handling. Once conditions suitable for pathological changes develop, progression to disease in warm water environments is rapid (Sobhana, 2009).

Diseases are generally classified into infectious and non-infectious diseases. Infectious diseases of fish can be caused by viruses, bacteria, parasites, or fungi. Noninfectious diseases or abnormalities can result from environmental stress, contaminants, or nutritional deficiencies (Lio-Po et al., 2009).

Infectious Diseases

Viral diseases. Several viral diseases have been reported in finfish (Table 1). Virological research received new impetus following high mortalities in hatchery-bred juvenile fish soon after transfer to sea cages. With increasing awareness of virus-related diseases and new species of fish being selected for culture, more reports of known and new viral diseases are expected (Sobhana et al., 2009).

Bacterial diseases. Bacterial diseases have attracted considerable attention and voluminous information is available (Table 2). A great number of aquatic bacteria are opportunistic and under normal environmental conditions do not cause disease. They become pathogenic only when the host/environment balance is changed by raised stocking density, inadequate nutrition, deteriorated water quality, rough handling (e.g., net changing, grading), or other stress factors (Sobhana et al., 2009). Bacteria can be gram-negative, or gram-positive. Gram-negative bacteria include *Vibrio* spp. that are common bacterial flora associated with marine fish.

Parasitic diseases. Parasites are invertebrate organisms. Some are free-living and can become opportunistic parasites, others require hosts for survival and reproduction and are referred to as obligate parasites (Table 3). Both opportunistic and obligate parasites are found in fish hosts but most parasitic diseases in fish are caused by obligate parasites. A large variety of parasites have been reported in cultured marine fish. Some cause serious disease outbreaks in farmed fish, resulting in significant financial losses to fish farmers. Parasites either cause major disease outbreaks in cultured fish or contribute to chronic sub-clinical effects. Parasitic organisms affecting cultured fish are grouped into three main groups: protozoa, plathyhelminthes, and crustaceans (Seng et al., 2006).

Fungal diseases. Several species of fungi are responsible for a range of serious economically important diseases of fish (Table 4). However, far less is known about fungal diseases of fish compared to bacterial or viral diseases. Fungal infections are easily recognized by mold-like growths.

Noninfectious Diseases

In addition to infectious agents, environmental stress, contaminants, and nutritional deficiencies can cause serious diseases in fish culture, while inadequate diets and uncontrolled water quality can lead to secondary infection. Some types of physical injury are specific to caged fish, e.g., fin or skin damage caused by net abrasion in fish that are over-stocked, and susceptibility to pathogenic organisms in fish that are handled without due care (Sobhana et al., 2009). Caged marine fish are vulnerable to "red boil disease" (*Vibrio anguillarum*) following routine handling at polluted sites (Chua and Teng, 1980).

Neoplastic diseases. Tumors (or neoplasia) are masses of abnormal tissue growing in or on the body that more or less resemble the tissue from which they arise. Tumors serve no physiological function and can be benign or malignant. Types of neoplasm in fish generally parallel those in mammals. While etiology has rarely been adequately determined, some tumors are induced by carcinogens, some seem associated with viral pathogens, and some have a clear hereditary component. Tumors or neoplasm of fish may be grouped into four categories, based on the type of cells from which they arise: (a) epithelial tumor, (b) mesenchymal tumor, (c) pigment cell tumor, and (d) neural tumor (Sindermann, 1989). Most if not all kinds of neoplasms known in higher vertebrates have been identified in fish, although most research on fish neoplasms has concentrated on a few tumors, especially epithelial tumors. Tumors of fish, like those of higher vertebrates, occur in all major organs and cell types (Mawdesley-Thomas, 1975). Neoplasms in fish are species or family-specific (Schlumberger, 1957).

Genetic and environmentally induced diseases. In addition to abnormalities caused by pathogens, marine fish may present physiological or structural defects, or conditions that have genetic or environmental causes. Skeletal abnormalities include distortion of the jawbone, shortened opercula, lordosis, incomplete dorsal or ventral fins, and shortened vertebrae. Abnormalities include hunched backs, curved caudal peduncles, opercular reduction, and disoriented fin rays. Common abnormalities in larvae include "crossbite" of the jaw, "pugheadedness" caused by reduction of the frontal skull and upper jaw bones, "sucker mouth" caused by reduction of the upper and lower jaw bones, and opercular reduction or malformation.

The high rate of larvae abnormalities is one of the most important problems in fish culture. Many factors (genetic, environmental, nutritional) may be involved. Excessive egg density, mechanical shock, radiation, thermal shock, and salinity change are among the environmental influences known to induce malformations.

Observations of abnormalities in coastal/estuarine fish have increased substantially as a consequence of closer attention to the effects of pollution on fish stocks. Depending on the concentrations, contaminants may result in mortality or a spectrum of sublethal effects including morphological and physiological abnormalities that can affect any life stage. Changes in flesh consistency, loss of weight, external lesions, exophthalmia, papillomas, and skeletal anomalies ranging from subtle modifications in gill arch structures or fin rays to extreme vertebral deformation have been noted in fish from grossly polluted waters (Sindermann, 1989).

Nutritional deficiency diseases. Deficiency diseases include those caused by insufficient thiamin or vitamin E and hepatomas associated with aflatoxin from stored fungi. Malnourishment or undernourishment of cultured fish can result in slow growth, susceptibility to disease, or death. Gall bladders may be affected by an amorphous, non-crystalline white to yellow substance while the columnar epithelial cells of the lumen of the gall bladder exhibit varying degrees of vacuolation. This condition is thought to be related to an improper diet and is, apparently, non-infectious. Fatty liver degeneration is also associated with dietary deficiency, probably of protein. Gross signs include poor growth, emaciation, listlessness, and cessation of feeding. Affected fish have a light tan liver and severely anemic blood. Nutritional deficiency diseases can be controlled by providing complete diets (Sindermann, 1977).

Conclusion

Aquaculture needs to expand horizontally and vertically to meet the growing demand for fish, especially marine fish. Most mariculture systems are located in open offshore waters, which makes control of pathogenic infections much more difficult than in freshwater culture systems (Ogawa, 1996). Under these conditions, the prevalence and spread of infectious diseases will inevitably increase as a result of higher infection pressure, deterioration of the environment, and crowded conditions, especially in intensive culture systems. Accordingly, effective control of infectious diseases has become more and more important in the cultivation of aquatic animals. Good health management is the best way to control disease. This includes the use of healthy fry, proper quarantine measures, optimized feeding, good husbandry techniques, disease monitoring (surveillance and reporting), and sanitation as well as vaccination and biosecurity measures when diseases occur (Sobhana, 2009). Overall, the emphasis must be on prophylaxis rather than therapy.

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Table 1. Viral diseases.

No.	*Disease and causative agent*	*Affected species*	*Target organ*	*Clinical signs*	*Gross pathology*	*Reference*
1	Infectious Pancreatic Necrosis (IPN) Birnavirus	Trout (rainbow, brook, brown), salmon (Atlantic, Pacific), yellow tail, halibut, pikes, perches	Pancreas, liver	Fish lie on bottom, swim with corkscrew motion; whitish fecal casts, swollen belly, darkening of body, gills typically pale, exophthalmia (pop eye)	Destruction of entire acinar pancreas, petechial hemorrhages of pyloric caecae, severe damage in pancreas and intestine, necrotic changes in kidney and liver	McKnight & Roberts, 1976 OIE, 2000
2	Viral Hemorrhagic Septicemia (VHS) Novirhabdovirus	Salmon, trout, herring, halibut, haddock, Japanese flounder, pike, seabass	Vascular system, kidney	Slight darkening of body color, exophthalmia (pop eye), bleeding around eyes, skin ulceration, pale gills with pinpoint hemorrhages	Swollen abdomen, marked by ascites; pinpoint hemorrhages in the fatty tissue, intestine, liver, swim bladder and muscle; pale liver with evidence of hemorrhages on surface; extensive focal necrosis in kidney, liver, and spleen	Wolf, 1988 Mortensen, 1999 Kurath & Winton, 2008
3	Infectious Hematopoietic Necrosis (IHNV) Rhabdovirus	Salmon (sockeye, Chinook, pink, chum, Atlantic), trout, herring, perch, pike, turbot	Kidney, spleen, liver	Lethargy, sporadic hyperactivity, darkening of the skin, anorexia, exophthalmia, possible long white discharge from anus, bleeding at base of fins	Stomach empty of food but swollen with a gelatinous substance; pale internal organs; degenerative necrosis in hematopoietic tissues, kidney, spleen , liver, pancreas, and gastro-intestinal tract	Wolf, 1988 Yasutake, 1978 Park et al., 1993 Penaranda et al., 2009
4	Lymphocystis disease (LCDV) Iridovirus	Flounder, flat fish, herrings, smelts, batfish, killifish, scorpion fish, sea bass, sunfish, perches, snappers	Lymphocytes, epidermal cells	Cauliflower-like lesions on body surface viz. mouth, fin, and tail; swimming affected; gray coloration; aggression and cannibalization of lesions	Virus is typically dermatotrophic and superficial, much like that of warts; is macroscopic in the lesions and occurs mostly at the periphery of the vascular system; extreme hypertrophy of fibroblast cells	Perkins et al., 1972 Shelton & Wilson, 1973 Bowden et al., 1995
5	Viral Nervous Necrosis (VNN) Nodavirus	Seabass, grouper, halibut, parrot fish, stripped jack, flounder, tiger puffer	Nervous system	Cork-screwing, whirling, darting and belly-up motion, swim bladder hyperinflation, cessation of feeding, pale gray body pigmentation	Vacuolated lesions in the central nervous system and inclusion bodies	Wolf, 1988 Munday et al., 2002 Nakai et al., 2009
6	Iridoviral disease (IVD) Iridovirus	White sturgeon, red sea bream, barramundi, Japanese flounder, horse mackerel, chicken grunt, estuarine rock cod	Gills, spleen, other internal organs	Lethargy, cessation of feeding, pale discoloration of body	Severe anemia, pinpoint hemorrhage of the gills, enlarged spleen, crystalline rodlike bodies in cytoplasm, hyperplasia of gills followed by necrosis of pillar cells	Wolf, 1988 Yasutake, 1978
7	Epizootic Hematopoietic Necrosis (EHN) Ranavirus	Rainbow trout, perch (redfin, macquarie, silver), sheat fish	Liver, kidney, spleen, other parenchymal tissues	Distended abdomen, darkened skin color, petechial (pinpoint) hemorrhages at base of fins, hemorrhaging of the gills	Acute focal, multifocal, or locally extensive coagulative or liquefactive necrosis of liver, hematopoietic kidney, and spleen; a small number of basophilic intracyto-plasmic inclusion bodies may be seen, particularly in areas immediately surrounding necrotic areas in the liver and kidney	Whittington et al., 1999, 2010 OIE, 2000
8	Spring Viremia of Carp (SVC) Rhabdovirus	Rainbow trout, pike	Liver, kidney, spleen, gills, brain	Exophthalmia; pale gills; hemorrhages on the skin, bases of fins, and vent; abdominal distension or dropsy and a protruding vent (anus), often with trailing mucoid fecal casts	Excess ascitic fluid in the abdominal cavity, degeneration of the gill lamellae and inflammation of the intestine; oedema and hemorrhage of visceral organs is commonly observed; focal hemorrhages may be seen in the muscle and fat tissue, as well as in the swim bladder	Ahne, 1985 Fijan, 1999 Goodwin et al., 2004 Goodwin, 2009

9	*Oncorhynchus masou* Virus Disease (OMVD) Herpesvirus	Salmon, rainbow trout	Skin, gill, liver, kidney, spleen	Lethargy, anorexia, darkening of the body, skin ulcers, petechiae; many fish die; tumors occur mainly on the jaws but also on the fins, operculum, cornea, and body surface	Edema and hemorrhages. skin ulcers, white spots on the liver. neoplasia around mouthparts or on body surface; tumors may also be found in the kidney; skin ulcers, intestinal hemorrhages, and white spots on the liver can occur in rainbow trout.	Yoshimizu et al., 1993 OIE, 2000
10	Infectious Salmon Anemia (ISA) Orthomyxovirus	Atlantic salmon, rainbow trout, cod, pollock	Endothelial cells in heart, liver, spleen, and kidney	Pale gills (except in the case of blood stasis in the gills), exophthalmia, distended abdomen, blood in the anterior eye chamber, and sometimes skin hemorrhages especially of the abdomen, scale pocket oedema	Yellowish or blood-tinged fluid in peritoneal and pericardial cavities; oedema of the swim bladder; small hemorrhages of the visceral and parietal peritoneum; dark redness of intestinal wall mucosa in blind sacs, mid-gut, and hind-gut; lacking blood in the gut lumen of fresh specimens; focal or diffusely dark red liver	Thorud & Djupvik, 1988 Kawaoka et al., 2005

Table 2. Bacterial diseases.

No.	*Disease and causative agent*	*Affected species*	*Target organ*	*Clinical signs*	*Gross pathology*	*Reference*
Gram-negative						
1	Vibriosis *Vibrio anguillarum, V. alginolyticus, V. ordalli, V.vulnificus, V. harveyi, V. damsella*	Salmon, trout, eel (Japanese , European), ayu, turbot, seabass, seabream, cod	Skin	Anorexia, abdominal distension, darkening of body, exophthalmia, sudden death in young fish, generalized septicaemia with hemorrhage on the base of fins, exophthalmia, corneal opacity	Spleenomegaly; liquefaction of spleen and kidney; petechiation of peritoneum; cardiac myopathy in acute form and deep granulamatous muscle lesions on various body parts in chronic form	Muroga et al., 1979 Colorni et al., 1981 Lamas et al., 1990 Fouz et al., 1992 Austin & Austin, 1993 Hjeltnes & Roberts, 1993 Toranzo et al., 2005
2	Flexibacteriosis *Flexibacteriosis Tenacibaculum maritimum* (formerly *Flexibacter maritimus*)	Turbot, salmonids, sole, seabass, seabream, flounder, Dover sole, Atlantic salmon	Skin, gills	Ulcers, reddening, erosion of skin, yellow mucoid material on skin, eroded and hemorrhagic mouth, ulcerative skin lesions, frayed fins, tail rot	Primary epithelial disease, erosive skin, and gill lesion that may become systemic; whitish plaques that may have red periphery on the head, back, or fins; sloughing of epithelium	Wakabayashi et al., 1986 Baxa et al., 1987 Toranzo et al., 2005
3	Bacterial Kidney Disease (BKD) *Renibacterium salmoninarum*	Atlantic salmon, bartail flathead, trout (brook, brown, rainbow trout), Chinook salmon, flathead minnow, Pacific herring	Spleen, kidney, visceral organs	Exophthalmia (pop eye), distended stomachs, skin lesions, darkening of skin, hemorrhages at base of the fins or at the vent, small ulcerations due to the rupture of small cutaneous vesicles	Creamy white granulomas in kidney and sometimes in liver and spleen, fluid in stomach cavity, hemorrhages on abdominal wall and in the viscera, enlarged spleen, holes in muscle blocks	Traxler & Bell, 1988 Evelyn, 1993 Wiens & Kaattary, 1999
4	Furunculosis *Aeromonas salmonicida*	Atlantic salmon, trout, Japanese eel, cod, halibut, pike, sea bream, turbot, striped bass	Skin, muscle, liver, spleen, kidney	Lethargy, cessation of feeding, deep ulcerative lesions, exopthalmos, swollen abdomen, respiratory distress and random jumping from water immediately before an outbreak	Skin ulcers and furuncles, hemorrhages in muscle and internal organs, enlarged spleen and focal necrosis of the liver; stomach filled with mucus, blood, and sloughed epithelial cells; congested intestine, fusion of gill lamellae	Herman, 1968 Roberts, 1989a Munro & Hastings, 1993 Toranzo et al., 2005
5	Piscirickettsiosis *Piscirickettsia*	Salmon (Chinook, chum, sockeye, pink, Atlantic, sakura),	Skin, liver, spleen, kidney	Whitish to reddish skin, ulcers, lethargy, circling, cessation of feeding, emaciation, respiratory distress,	Pale gills, systemic vasculitis with granulamatous inflammation, gray swollen spleen and kidneys, mottled to spotted liver with large pale necrotic	Turnbull, 1993 Birrell et al., 2003

	salmonis, Rickettsia-like organisms	rainbow trout		swimming at the sides of net pens, anorexia	lesions, pinpoint hemorrhages of the stomach organs and flank muscle	
6	Pasteurellosis *Pasteurella piscida*	White perch, sea bream (black, red), ayu, red grouper, yellow tail, seabass, sole	Spleen, liver, pancreas	Lethargy; occasional darkened spots on the body surface; diseased fish rapidly lose their vigor, sink to the bottom, and die	Small hemorrhages around gill covers or the base of fins; necrosis of spleen, liver, and pancreas; multiple raised white nodules on spleen and kidney	Snieszko et al., 1964 Hawke et al., 1987 Kitao, 1993a Magarinos et al., 2003
7	Fin rot *Pseudomonas fluorescens, P. putida, P. putrefaciens*	Hybrid striped bass, rainbow trout, European eel, sea bream, ayu, turbot	Fins	Fin erosion, anorexia, inactivity, skin discoloration, emaciation	Typical bacterial septicemia, ulceration, hemorrhages at the site of infection	Bauer et al., 1973 Nakai et al., 1985 Lopez-Romalde et al., 2003
8	Edwardsiellosis *Edwardsiella tarda*	Striped bass, Japanese eel, Japanese flounder, red sea bream, crayfish, striped mullet	Multi organ infection	Hypoxia; swollen abdomen; lesions on body surface, flanks, and caudal peduncle; petechial hemorrhages, skin depigmentation	Epithelial hyperplasia that can give fish a tarred appearance, necrosis in the lateral line of body surface and gills, anemia; white bacteria-filled nodules in gills, kidney, liver, spleen, and intestine	Meyer & Bullock, 1973 Kubota et al., 1981 Herman and Bullock, 1986
9	Enteric red mouth *Yersinia ruckeri*	Salmon, trout, seabass, sturgeon, turbot, whitefish, Arctic char	Skin, internal organs	Abdominal distension, unilateral or bilateral exophthalmos, hyphema	Leucocytosis, reticulocytosis, low hematocrit; hemorrhage of gills, kidney, liver, spleen, heart, and muscle; anemia	Frerichs et al., 1985 Stevenson et al., 1993
Gram-positive						
10	Streptococcosis *Streptococcus iniae, S. shiloi, S. difficile*	Striped mullet, croaker, yellow tail, ayu, sea bream (red, wrasse), siganids, red drum	central nervous system, internal organs	Exophthalmia, hemorrhages on the body, darkening of the body, erratic swimming, abdominal distention	Sersanguinous fluid in peritoneal cavity and intestine; meningoencephalitis; hemorrhage in the intestine, liver, spleen, and kidney; necroses of the heart, gill, skin, and eye	Plumb et al., 1974 Baya et al., 1990 Kitao, 1993b Ravelo et al., 2001 Colorni et al., 2002 Sobhana, 2009
11	*Staphylococcus epidermis*	Red sea bream, yellow tail	Skin	Exophthalmia, skin ulcers	Disease reported only once	Kusuda & Sugiyama, 1981
12	Nocardiosis *Nocardia asteroides N. campuchi*	Largemouth bass, Pacific salmon, rainbow trout, jack mackerel, yellow tail	Skin, muscle, internal organs	Anorexia, inactivity, skin discoloration, emaciation	Short coccobacilliary to long slender branching rods in chronic inflammatory lesions may ulcerate or extend to skeletal muscle and visceral organs causing abdominal distension	Wood & Ordal, 1958 Conroy, 1964 Van Duijn, 1981 Sobhana, 2009
13	Mycobacteriosis *Mycobacterium marinum*	European sea bass, striped bass, red drum, cod, halibut, Atlantic mackerel, rabbit fish	Skin, kidney, liver, spleen	Superficial ulcers and exophthalmia, scale loss accompanied by hemorrhagic lesions penetrating the musculature	Spleen and kidney are enlarged with granulomatous lesions that appear macroscopically as whitish nodules; in advanced cases these lesions spread to liver, heart, mesentery, etc.	Hederick et al., 1987 Colorni, 1992 Diamant et al., 2000
14	Botulism *Clostridium botulinum*	Rainbow trout, coho salmon	Skin, internal organs	Dark color, slightly swollen; fish float listlessly on the surface then sink lifeless to the bottom	Pallor of the gills, slight abdominal oedema, an empty digestive tract	Cann & Taylor, 1982 Eklund et al., 1982 Roberts, 1989b

Table 3. Parasitic diseases.

No.	*Causative agent*	*Affected species*	*Target organ*	*Clinical signs*	*Gross pathology*	*Reference*
1	Ciliates *Cryptocaryon irritans*	E*pinephelus* spp., *Lutjanus* spp., *Lates calcarifer, Trachinotus blochii*	Gills, body surface	Whitish spot on body surface, darkened body, lethargy, exophthalmia, increased mucus production, rubbing body surface against net	Petechial hemorrhages in the skin, excess mucus production, skin ulcers with secondary *Pseudomonas* spp. infections	Nigrelli & Ruggieri, 1966
	Ciliates *Tricodina* spp	Salmonids, cod, eels, Gobiidae, Sygnathidae	Skin, gills, fins, urinary tract	Lethargy, non-feeding, pale gills with increased mucus production, rubbing body surface against net	Hyperplasia and necrosis of epidermis, extensive desquamation of epithelium	Arthur & Margolis, 1984
	Ciliates *Brooklynella* spp.	Marine teleosts	Gills	Lethargy, non-feeding, rubbing body surface against net	Destruction of gill surface tissue, hemorrhages in the gills, desquamation, cell proliferation and other tissue reactions	Lom & Nigrelli, 1970
2	Dinoflagellates *Amyloodinium ocellatum*	Striped bass, redfish, gray mullet, snapper, European seabass	Gills, body surface	Fish gather at water surface or aeration outlet, rapid gill operculum movement, pale gills, darkened body, increased mucus production in gills	Trophonts in pseudobranch, branchial cavity, and nasal passages; gill hyperplasia, inflammation, hemorrhage and necrosis, osmoregulatory impairment	Paperna, 1980
3	Myxosporeans *Sphaerospora* spp.	European seabass, striped bass, redfish, grouper	Kidney, liver, spleen, intestine	Loss of equilibrium, floating upside down, some with swollen abdomen and hemorrhages on mouth and body surface	Hypertrophy of cartilage and inflammation of surrounding tissues, granulomas in organ of balance, lesions in vertebral column and depression in cranium, mandibular and vertebral deformity	Lom & Dykova, 1992
4	Microsporidians *Glugea* spp. *Pleistophora* spp.	Ayu, *Pleuronectes*, plaice, flounders, *Pseudopleuronectes*	Multi organ infection	Swollen abdomen, black nodules on internal organs	Intestinal lesions, white cyst-like xenoma formation in subepithelial connective tissues causing thickening of intestinal wall, atrophy of epithelium and luminal occlusion	McVicar, 1975 Cali & Takvorian, 2003
5	Capsalid monogeneans (skin flukes) *Benedenia* spp. *Neobenedenia* spp.	Japanese yellow tail, Japanese flounder	Body surface	Darkened body, erratic swimming behavior, rubbing against net, pale gills, lethargy and loss of appetite, opaque eyes	Patches of "dryness" on scales or loss of scales on forehead (above the eyes), hemorrhage and necrosis on body surface	Egusa, 1983
	Diplectanic monogeneans (gill flukes) *Diplectenum* spp.	Sea bass	Gills	Darkened body, rubbing against net, pale gills, lethargy, loss of appetite	Hemorrhages in gills, hyperproduction of mucus, inflammation and hyperplasia of gill epithelium with inclusion of leucocytes, fusion of gill lamellae	Paperna & Laurencin, 1979
	Dactylogyrid mono-geneans (gill flukes) *Haliotrema* spp. *Dactylogyrus* spp.	Brown trout, yellow tail, Japanese flounder, red sea bream	Gills	Darkened body, pale gills, lethargy, loss of appetite, excess mucus production	Attachment of the worm induces extensive reaction on gill tissue with hyperplasia of epithelial cells and mucus cells, clubbing of filaments and fusion of lamellae	Ogawa & Egusa, 1976
	Microcotylids monogenean (gill flukes) *Heterobothrium* spp., *Heteraxine*	Trout (rainbow, brown), yellow tail, Japanese flounder, red sea bream	Gills	Lethargy, anorexia; pale gills, muscle, and kidney; loss of appetite, anemia	Extensive hyperplasia and tissue destruction at the site of attachment, severe anemia in host tissue, low blood counts, high urea and creatinine	Egusa, 1983 Kim & Cho, 2000 Ogawa, 2002

	spp., *Microcotyle* spp.					
6	Copepods *Caligus* spp. (sea lice), *Pseudocaligus* spp., *Lernanthropus latis*	Atlantic salmon, black sea bream, Malabar rock cod, giant perch, yellow tail, milk fish	Skin	Lethargy at the water surface, erosion of scales, loss of appetite, pale gills, excess mucus production	Subepidermal hemorrhaging and erosion of skin expose cranial bones at high level of infection; oedema, hyperplasia, sloughing of epidermal cells and inflammation caused by attachment, tenency to secondary bacterial and fungal infection	Costello, 1993
7	Isopods *Rhexanella sp.* *Nerocila sp.*	Mugilidae, Sparidae, Carangidae, Molidae, Holochepalidae	Skin, gills, buccal cavity	Loss of appetite, rub body against object on side of net, sluggish swimming, rapid gill operculum movement	Necrosis of skin and gill filaments, loss of gill filaments, atrophy of gill filaments, skin lesions	Bruce, 1987 Trilles, 1991
8	Hirudinea (leech) *Zeylanicobdella arugamensis*	*Ephinephelus coioides*	Fins, skin	Frayed fins, loss of appetite, sluggish swimming.	Inflammation, displacement and erosion of dermis, hyperplasia of epithelium, massive infiltration of inflammatory cells at site of attachment	Cruz-Lacierda & Burreson, 2000

Table 4. Fungal diseases.

No.	*Disease and causative agent*	*Affected species*	*Target organ*	*Clinical signs*	*Gross pathology*	*Reference*
1	Saprolegniasis *Saprolegnia parasitica*	Salmon, Japanese eel, pike, sea bass, lamprey, sturgeon, mullet, tilapia	Epidermal tissues, fins	Cotton-like appearance that radiates out in a circular, crescent-shaped, or whorled pattern; lethargy, loss of equilibrium, visible white or gray patches of filamentous mycelium, discoloration of body	Tissue destruction and loss of epithelial integrity, cellular necrosis, dermal or epidermal damage, hyphae penetration to basement membrane, hemodilution, leads to death	Roberts, 1989b Meyer, 1991 Bruno & Wood, 1994 Hatai & Hoshiai, 1994
2	Ichthyophoniasis *Ichthyophonus hoferi*	Herring, sprat, flounder, flat fish, mackerel, Atlantic cod, plaice, brown trout	Skin, heart, liver, kidney, brain	Roughened skin (sand paper effect), lean and slender appearance of the body, emaciation, swelling of organs, distinctive off odor	Spores and fungal hyphae in the spleen, lumina of kidney tubules, and muscles below; hemorrhages, sores, and papillomas; creamy white nodules in the heart, chronic systemic granulomatous inflammation, cirrhosis and atrophy of affected organs, massive tissue invasion and necrosis, leads to death	Miyazaki & Kubota, 1977 Alderman, 1982 Sindermann & Chenoweth, 1993 Hodneland et al., 1997
3	*Aphanomyces invadens*	Atlantic menhaden, black bull head, blue gills, American shad, striped mullet, largemouth bass, silver perch	Skin, internal organs	Ulcers, commonly oval in shape with irregular margins and a creamy to red coloration at the center; slimy patches in the skin, cloudy eyes, discoloration of body	Extensive myonecrosis, granulomatous myositis, vacuolation, granulomatous inflammation, necrotic tissue debris and inflammatory cells in skeletal muscle, tissue necrosis and debris associated with masses of free-hyphae focal-advanced deeply-penetrating ulcers that expose underlying musculature	Fraser et al., 1992 Blazer et al., 2002 Hawke et al., 2003
4	Branchiomycosis *Branchiomyces demigrans*	Large-mouth bass, striped bass, northern pike	Gill	Gills may be mottled in appearance, discoloration of gill tissue, fusion of gill lamellae, penetration of fungal hyphae into the blood vessels of gills	Hyperplasia and areas of massive necrosis resulting from thrombosis of vessels by fungal hyphae with talengiectasis and vascular necrosis	Wolke, 1975 Alderman, 1982