Persistent and Emerging Diseases of Freshwater and Marine Fishes in the Southeast: Implications for Fishery Management

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Abstract: Several diseases of fish present challenges to both fishery managers and aquaculturists in the Southeast. Emerging diseases along with a suite of known and persistent diseases can present management challenges for native species and biodiversity, can cause loss of recreational fishing opportunities, and can affect local economies or reduce profitability in commercial aquaculture. Emerging diseases such as mycobacteriosis in striped bass, epizootic ulcerative syndrome in menhaden, and spring viremia of carp present some new challenges to fishery managers. Likewise, recurring epizootics resulting from such etiologic agents as *Streptococcus* and *Vibrio* in estuarine fishes or *Aeromonas* and *Edwardsiella* in freshwater fishes have challenged managers for decades. Pathogens including *Photobacterium damselae piscicida* and several of the *Mycobacterium* species may represent health risks to managers, anglers, or fish culturists. Successful resource management depends on the ability of fishery managers to clearly understand the etiology of infectious diseases to both wild and hatchery stocks so that effective management and control strategies may be implemented. The needs for adaptive fisheries management strategies that employ fish health and disease considerations are discussed.

Key words: disease, pathogens, fishes, adaptive management

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A quick look at the index of most standard textbooks on fishery biology or management shows a general lack of attention to the effects of disease, whether infectious or non-infectious, on wild fish populations. Clearly, from a historical perspective the vast majority of presentations regarding the effects of disease on fish highlight those influencing the production of fish in public hatcheries or commercial aquaculture facilities. Most of the research on fish diseases, the development of treatment protocols, and the evolution of novel vaccines and other therapeutants have resulted from a need to rear fish in captivity for either the restoration of native stocks, the enhancement of recreational fishing opportunities, or the production of fish for food or other economic gain. Allison (1954) and Snieszko (1970) provided excellent reviews of the roles of fish disease in fish culture. However, as noted by Goede (1986), one of the reasons that disease control programs fail is that "traditional fishery managers tend to place fish diseases in a black box and consider them only vaguely as causing mortality."

Fish, like people and all other living things, suffer from the effects of parasites, pathogens and other anomalies. Disease is "any impairment that interferes with or modifies the performance of normal functions, including responses to environmental factors such as toxicants and climate, nutrition, infectious agents, inherent or congenital defects, or any combination of these factors" (Wobester 1981). Diseases often go unnoticed in aquatic organisms until such a time as it becomes epizootic and dead or dying fish become evident. It was not until the late 1800s that fishery biologists first recognized the role of bacterial pathogens as etiological agents in fish, and viral diseases were not described until the mid-1950s (Post 1987). However, as we now know, the restoration, recovery, and management of freshwater and marine fish can often become complicated by persistent or emerging infectious and non-infectious diseases. While many diseases are known to occur naturally in wild fish, the culture of fish for restoration or management purposes at Federal and State hatcheries or the production of fish in aquaculture can become seriously compromised by disease.

This paper provides a review of four of the more serious and/or emerging diseases of fish in the Southeast and additional information on several other fish diseases of concern to fishery managers. The intent is to provide fishery managers with information on some of the etiological aspects of these diseases, to increase awareness of the roles of infectious and non-infectious diseases in fishery management, and to discuss the importance of adaptive fishery management strategies that include considerations of the epizootiology of infectious diseases.

Important and Emerging Diseases

An understanding of the significance of diseases in cultured and wild populations of fish and other aquatic organisms is an important criterion for effective resource management. It has been well-documented that diseases adversely affect the survival, reproduction, and performance of their hosts. However, as pointed out by Hedrick (1998), the implications of disease are often overlooked in fishery management. Ten of the more serious or emerging diseases of fishes in the Southeast United States are summarized in Table 1. Of these, spring viremia of carp is a notifiable diseases listed by the Office International des Epizooties (OIE) in Paris, France, and epizootic ulcerative syndrome (EUS) is considered an OIE disease of concern. Both of these diseases are included in the OIE International Aquatic Animal Health Code. The code includes diseases known to cause significant production losses at national or multinational scales, affect economic or ecologically important wild aquatic animal populations, or represent a public health threat. These diseases typically resist or respond poorly to therapy, have restricted geographic ranges and affect species that are of high economic importance in international trade (OIE 2000). Controlling the spread of OIE-listed diseases through international trade is the primary objective of the code. All 162 of the OIE participating countries, including the United States, must notify the OIE of any first or new occurrence of any of the listed diseases, any new host for a pathogen, and any zoonotic potentials or risks for international spread of these diseases. Reporting in the United States is through the U.S. Department of Agriculture, Animal and Plant Health Inspection Service.

The pathogens and parasites listed in Table 1 are not inclusive of all diseases and maladies affecting wild and cultured fishes in the region, but includes those that have either consistently caused problems for managers or represent new, emerging diseases. For instance, outbreaks of gill maggots *(Achtheres pimelodi)* in several reservoir populations of striped bass *(Morone saxatilis)* in Tennessee and Virginia recently captured the attention of recreational anglers, the news media, and fishery managers. Epizootics caused by gill maggots have been reported elsewhere in striped bass, as well as in other species such as smallmouth bass *(Micropterus dolomieu),* rock bass *(Ambloplites rupestris),* and several species of ictalurids. Another example of a relatively infrequent disease is the recent kills of carp in Santee Cooper and Lake Moultrie, South Carolina, which were likely caused by an atypical *Aeromonas* infection.

The following sections provide details on four persistent and potentially important diseases having fishery management implications in the Southeast United States.

Epizootic Ulcerative Syndrome (EUS)

This atypical oomycete infection, also known as red spot disease, ulcerative mycosis or mycotic granulomatosis, is a serious worldwide disease of freshwater and estuarine fishes and one of several dermatological diseases affecting estuarine fishes in the southeast. The disease was first described in cultured populations of goldfish *(Carassius auratus)* and ayu *(Plecoglossus altivelis)* in Japan during the 1970s (Miyazaki and Egusa 1972). In the Australo-Pacific Region and throughout southeast Asia it is known to cause serious economic losses in aquaculture. The disease was first reported in the United States in 1984 from several species of estuarine fishes in the Tar-Pamlico Estuary, North Carolina (Noga et al. 1999), and has since been identified from fishes along the Atlantic coast from Long Island to Florida (Blazer et al. 2002). The disease seems to be most pronounced in populations of Atlantic menhaden *(Brevoortia tyrannus)* but is also known to occur in other estuarine species such as striped mullet *(Mugil cephalus).* It has also been observed in freshwater populations of bluegill *(Lepomis macrochirus),* channel catfish *(Ictalurus punctatus),* and black bullhead *(Ameiurus melas)* (Hawke et al. 2003).

The disease is typically represented by deep, extremely aggressive ulcers that often penetrate into the body cavity. The presence of deeply penetrating aseptate hyphae and severe chronic granulomatous inflammation offer a presumptive diagnosis (Noga 2000). Recent studies at the U.S. Geological Survey National Fish Health Research Laboratory and the Virginia Institute of Marine Science suggest that the etiologic agent for EUS in Atlantic menhaden in Chesapeake Bay is the oomycete *(Aphanomyces invadans)* (Blazer et al. 2002). Kiryu et al. (2002) fulfilled Koch's postulates by experimentally inducing characteristic lesions and pathology in menhaden by both inoculation and bath exposure by secondary zoospores. By fulfilling Koch's postulates Kiryu demonstrated that the pathogen isolated from diseased menhaden and subsequently cultured on artificial media would elicited the same disease response when reintroduced into healthy fish. Subsequent studies by scanning electron microscopy showed zoospores adhering to intact epidermis, germinating, and then penetrating the epithelium (Kiryu et al. 2003). The authors also found the

Table 1. Persistent and emerging diseases of freshwater and marine fishes in the Southeast.

Disease	Period of emergence	Geographic area of concern	Observations and comments
Striped Bass Gill Maggots	2000s	Tennessee, Virginia	Parasitic copepods *Achtheres pimelodi*
Asian Tapeworm	1980s	Continental U.S.	A serious exotic and parasitic cestode *Bothriocephalus acheilognathi* that affects many native cyprinids, carp, and some catfish species. Probably introduced along with grass carp and now a threat to many native cyprinids in the Colorado River.
Damselfish Neurofibromatosis	1980s	Florida and Caribbean coral reefs	A transmissible cancer that affects bicolor damselfish on South Florida reefs. The disease exhibits many traits in common with neurofibromatosis type-1 in humans, including multiple plexiform neurofibromas and areas of hyperpigmentation (Schmale and Kemerer 1996).
Spring Viremia of Carp Virus	Late 1990s	North Carolina, Wisconsin, Mississippi River Drainage	Serious threat to both aquaculture industry and potentially to native fish populations. This rhabdovirus was first documented in an aquaculture facility in North Carolina and later reported in wild carp from the Mississippi River in Wisconsin.
Koi Herpesvirus	1998	Mid-Atlantic and Southern California	Epizootics involving common carp and koi document ed in the mid-Atlantic during 1998. Discoloration and severe necrosis of the gills is the most consistent sign of the disease. Additional outbreaks in koi occurred in southern California in 1999 (Gray et al. 2002).
Largemouth Bass Virus	Mid-1990s	17 Southeast and Southwest states	An iridovirus first isolated from largemouth bass from Lake Weir, FL (Grizzle et al. 2002), and linked to largemouth bass mortalities at Santee-Cooper Reservoir, SC, in 1995 (Plumb et al. 1996). Transmissible in water and orally (Woodland et al. 2002).
Streptococcal Septicemia	1970s	US Atlantic and Gulf coastal waters and coral reefs	Known to occur worldwide and usually associated with poor water quality or environmental conditions. Well known in fish culture since the 1950s and as wild fish epizootics since the 1970s. Most recently implicated as the causative agent in mass mortalities of coral reef fishes in the southeast Caribbean (Fergu son et al. 2000).
Mycobacteriosis	Mid-1990s	Coastal waters	A subacute to chronic wasting disease known to affect 167 species of freshwater and saltwater fishes and occurring in all coastal waters of the U.S. *Mycobacterium marinum* is considered the primary causative agent although seven *Mycobacterium* species may be involved (Rhodes et al. 2001). Can be pathogenic to humans as "fish-handler's disease."
Epizootic Ulcerative Syndrome	1984	Coastal waters	Widespread disease in estuarine fish along the US Atlantic coast caused by the *Aphanomyces invadans.* Initially called mycotic granulomatosis when first described in cultured goldfish and ayu in Japan. First recognized in North Carolina estuaries in 1984. High incidence of ulcerative lesions reported in Chesapeake Bay and Florida. Atlantic menhaden young-of-year are highly susceptible (Blazer et al. 2002).
Whirling Disease	1950s	Known to occur in 21 states	Chronic, debilitating disease caused by the parasite *Myxobolus cerebralis* is currently known to occur in at least 21 states. Generally considered a disease of cultured trout, several "blue ribbon" trout streams in Colorado and Montana in the early 1990s were severely affected (Potera 1997).

pathogen to cause disease at very low zoospore concentrations with a single zoospore capable of initiating an ulcer and leading to mortality in Atlantic menhaden. This demonstrated both the high susceptibility of the host and the virulence of the pathogen.

Stephenson and Landsberg (2002) recently examined histological slides from several Florida marine and estuarine fishes with external lesions and found that salinity plays an important role in the progression of the disease. Tissues from fish in areas of higher salinity (>15 ppt) had more granulomas suggesting a more effective immune response to invading fungal hyphae than those at lower salinities. Tissues from fish in lower salinity waters were much more likely to have free hyphae and to exhibit lesions. This is consistent with the findings of Kiryu et al. (2002) in which secondary zoospores lost their infectivity in salinities above 4–6 ppt. This, in part, explains previous observations of Kator et al. (2002) in which fish in small embayments of the Chesapeake Bay exhibited a higher prevalence of lesions following periods of intense, episodic summer thunderstorms.

Kiryu et al. (2003) have shown *Aphanomyces invadans* to be a highly infectious, pathogenic, and invasive primary pathogen of Atlantic menhaden. However, the extent that EUS represents a threat to other estuarine fishes has yet to be fully documented. Other pathogens such as the parasite *Kudoa,* toxic dinoflagellates (e.g., *Pfiesteria* spp.) or virally induced lymphocystis can also cause skin lesions. As such, fishery managers need to use caution in attributing lesions to specific pathogens or diseases and should do so only after examination and confirmatory diagnostics by an aquatic animal health specialist or veterinarian.

Mycobacteriosis or Fish Tuberculosis

Mycobacteriosis is a widespread, chronic disease of freshwater and estuarine fishes. Several *Mycobacterium* species have been identified from and known to affect over 167 fish species (Rhodes et al. 2001). Infected fish generally show scale loss and hemorrhagic lesions that can, in severe infections, penetrate the musculature. Emaciation, exophthalmia, changes in pigmentation and spinal defects have also been observed (Gauthier et al. 2003). Internally, mycobacteriosis is typified by granulomas in spleen, kidney, and liver (Rhodes et al. 2001). Recent studies by scientists at the National Fish Health Research Laboratory and the Virginia Institute of Marine Science have shown infection rates in striped bass *(Morone saxatilis)* of nearly 76% in certain Virginia tributaries to the Chesapeake Bay. In addition, two new species of mycobacteria have been described from infected striped bass from the Chesapeake Bay. The roles of these species, *M. chesapeaki* and *M. shottsii,* have yet to be fully described but it is apparent that infections in striped bass often result from co-infections of two or more mycobacterial species (Gauthier et al. 2003).

Mycobacteriosis in fish usually results in internal lesions and typically the presence of external lesions are only found under highly stressful environmental conditions, mostly in aquaculture. As such, the atypical presentation of the disease in Chesapeake Bay is problematic. Striped bass with both internal and external lesions were reported by Overton et al. (2003) to be in significantly poorer condition than

those without lesions. The disease is known to result in emaciation, poor growth and retarded sexual maturation (Noga 2000).

The disease is epizootic in the Chesapeake Bay and has been so for several years and the high incidence of this disease suggests significant detrimental effects on wild populations of striped bass (Gauthier et al. 2003). While preliminary studies suggest that the disease is spread horizontally, the overall etiology of the disease is not known and the role of mycobacteriosis in mortality of striped bass has yet to be evaluated. The effects of this disease on age-specific mortality and reproductive function need to be assessed and incorporated into existing fishery regulatory models.

Spring Viremia of Carp

Spring viremia of carp (SVC) is an emerging disease in carp *(Cyprinus carpio)* and carp-like cyprinids in the Southeast. It is a serious, highly contagious disease primarily of cultured carp and koi. The disease is caused by a rhabdovirus that results in an acute systemic disease. It is a serious disease in aquaculture in western and eastern Europe, the former Soviet Union, and in Israel. Susceptible species include common carp, grass carp *(Ctenopharyngodon idella),* silver carp *(Hypophthalmichthys molitrix),* bighead carp *(Aristichthys nobilis),* crucian carp *(Carassius carassius),* goldfish *(Carassius auratus),* tench *(Tinca tinca),* and sheatfish *(Silurus glanis)* (Wolf 1988).

Typically, SVC occurs at water temperatures of < 18 C and is most prevalent in the spring. Infections occur at higher temperatures, but clinical disease does not develop. The rhabdovirus that causes SVC enters the fish through the gills and replicates within the epithelium (Ahne 1978). Virus within mucoid casts of infected fish feces can spread the disease. Leeches and the fish louse *(Argulus),* have been shown to vector the pathogen to fish (Ahne 1978). Infected fish become lethargic, respire slowly, and most often lie on the bottom of production ponds. The external signs of infection include dark pigmentation, pronounced enlargement of the abdomen, exophthalmia, pale gills, and an inflamed anus. Internally, fish exhibit peritonitis and hemorrhages in the kidney, liver, and swim bladder (Plumb et al. 1999).

The first case in North America was reported in 2002 from a koi hatchery in Kernersville, North Carolina. The disease was diagnosed at the University of Arkansas Diagnostic Laboratory at Pine Bluff. Subsequent to the outbreak in North Carolina, biologists from the Wisconsin Department of Natural Resources and the U.S. Fish and Wildlife Service reported an outbreak in wild carp at Cedar Lake in northwestern Wisconsin. The U.S. Fish and Wildlife Service's Fish Health Center in La Crosse, Wisconsin, described a second record in wild fish from carp taken from the Calumet-Sag channel near Chicago. While the number of North American fish species susceptible to SVC is not known, the disease is of particular concern in the Southeast where many endangered native fishes, particularly cyprinids, reside (Walsh et al. 1995). The disease is also a serious concern for the wild caught and cultured baitfish industry (Goodwin et al. 2004). As noted earlier, it is also an OIE notifiable disease and outbreaks need to be reported to the U.S. Department of Agriculture, Animal and Plant Health Inspection Service for international reporting.

Streptococcal Septicemia

Streptococcal infections can occur in marine, estuarine, and freshwater fish populations. This gram-positive aerobic bacterium is known to cause a rapidly fatal disease in many tropical marine fishes. Infected fish are typically lethargic and exhibit exophthalmia, hemorrhagic lesions, exhibit bloody fluid in the peritoneal cavity and intestine, and greatly enlarged and sometimes black spleens. There can also be inflammation of the pericardium and a marked fibrinous inflammatory response on the surface of the myocardium (Plumb 1999). Several species of *Streptococcus* have been isolated from infected fish and infected fish may harbor polymicrobial infections involving the genera *Streptococcus, Enterococcus,* and *Mycobacterium.*

Outbreaks in marine or brackish water fish are usually more severe than those occurring in freshwater and epizootics in wild fish are most often associated with degraded environmental conditions (Plumb 1999). Fish kills along the Gulf of Mexico in the early 1970s attributed to *Streptococcus* spp. infections occurred during a period of low rainfall, restricted flow to the open Gulf waters, and poor water quality (Plumb et al. 1974). Likewise, Cook and Lofton (1975) confirmed that the pathogen was in part responsible for the epizootics along the Alabama coast and the northwest coast of Florida. Ferguson et al. (2000) attributed a massive kill of reef fishes in the southeast Caribbean to *Streptococcus iniae* and Baya et al. (1990) attributed mortality of striped bass in Maryland waters of Chesapeake Bay to the same pathogen. The pathogen is also a common problem in baitfish production (Post 1987) and is known to be a serious pathogen in tilapia and hybrid striped bass culture particularly in recycled water systems (Plumb 1999).

Fishery Management Implications and Concerns for Zoonotic Disease

In addition to causing disease to many species of freshwater and marine fishes there are a few pathogens that are known to be zoonotic, that is, causing disease in humans. While the risk of contracting an infection or disease due to known fish pathogens is generally low, an awareness of the potential risks is important for both fish culturists and fishery managers. For instance, the handling of fish infected with *Mycobacterium marinum* by anglers, commercial fishers, or fishery management workers represents a potential health risk. Fish-pathogenic mycobacteria are zoonotic and can cause localized skin lesions that can be very difficult to treat (Noga 2000). Immuno-compromised individuals can be especially at risk of infection (Glaser et al. 1994). Rhodes et al. (2001) hypothesized that an epizootic of mycobacteriosis in Chesapeake Bay striped bass may serve as a reservoir for transmission of mycobacterial infections to humans. In 2001, the Maryland State Public Health Laboratory reported 34 positive cases of mycobacteriosis, or Fish-Handler's Disease, in humans (Blankenship 2002).

Other common fish pathogens such as the motile aeromonads and vibrios can cause disease in fishery workers or anglers. The motile aeromonads (e.g., *Aeromonas hydrophila*) are some of the most common bacterial diseases of freshwater fishes while the vibrios (e.g., *Vibrio anguillarum,* the cause of salt water furunculosis)

maintain the same stature for marine fishes. Some of the motile aeromonads are known to cause gastrointestinal disorders and systemic infections in humans and *Photobacterium damsela piscicida* (formerly *Vibrio damsela*) is known to cause skin ulcers (Noga 2000). *Aeromonas hydrophila* may cause septic arthritis, diarrhea, corneal ulcers, meningitis, and assorted skin and wound infections in immuno-compromised humans (Ciprano 2001). In the catfish industry, workers in fish processing plants need to pay special attention to the risks of serious enteric diseases resulting from catfish infected with *Edwardsiella ictaluri* which causes enteric septicemia of catfish (ESC). The pathogen can cause gastroenteritis in humans but has also been implicated in some cases of meningitis and liver infections (Noga 2000). The careless handling of fish infected with *Streptococcus iniae* could result in several human conditions including skin lesions, chronic swelling of the lymph nodes, septicemia, and endocarditis (Lehane and Rawlin 2000).

In addition to zoonotic potentials, chronic infections by several of the pathogens listed in Table 1 and those previously discussed may affect population structure, reproductive success, and/or fitness of the infected host fish species. Infectious diseases that rapidly kill their hosts tend to become extinct locally (Lafferty and Gerber 2002). However, host species that are environmentally stressed or otherwise immuno-suppressed may be especially prone to infections and mortality due to chronic diseases (Scott 1988). Unfortunately, the effects of chronic diseases on fish populations are difficult to assess.

The application of new knowledge of fish disease processes, fish disease defense mechanisms, and fish culture and ecology is important to the development of overall fishery management strategies. This is especially true where either epizootic diseases or chronic diseases influence fish at the population level. In such instances, successful resource management will depend on the ability of managers to properly diagnosis a disease, to predict population and ecosystem level risks, and the ability to take appropriate actions for disease containment and control. Fishery managers should employ adaptive management techniques that incorporate aquatic animal health concerns whenever disease is implicated as a factor. Adaptive management is a process from which scientific knowledge is generated on an issue or resource and this knowledge is subsequently utilized to alter or formulate management strategies. The application of a strategy and the monitoring of the outcomes of it's implementation are essential components of this iterative process and are the key elements of active management. Under an active adaptive management scenario, management actions can be viewed as deliberate experiments aimed at addressing a specific management problem (Wilhere 2002).

The management of disease in fish production facilities by active adaptive management can be easily implemented with the supporting science, diagnostics and monitoring. However, such an approach in wild fish populations is more problematic. The high degrees of uncertainty and the general lack of abilities to control the system make adaptive management a challenge. Employing active adaptive management in such situations requires the coordination and cooperation of all the responsible authorities and the full integration of aquatic animal health specialists or veterinarians in strategic planning and monitoring. Addressing disease issues in wild

populations also require consultations with the policy makers that regulate the fishery and those that utilize the resource, namely anglers and commercial fishers. When any zoonotic risks exist this process should involve not only aquatic animal health specialists but also those responsible for public health. All of these actions are predicated on an understanding of the etiology of the infectious disease and having effective communication networks in place for sharing information, making decisions, and getting scientifically valid information to fishery workers, resource users and the public.

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