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The Impact of Diseases of Pen-Reared Salmonids on Coastal Marine Environments

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Please note,
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ABSTRACT

With the increase of mariculture, particularly netpen rearing of salmonids, there is a concern about the impact of these operations on the coastal marine environment. Models have been made to assess this impact, but these models have not considered the potential risk of increased disease in wild fishes that mariculture may impose. Diseases of captive fish may pose a threat to wild fish when they are exotic diseases, have the potential to cause an increase in prevalence of an enzootic disease, or if their presence results in the use of drugs that are released into the environment. The transmission and development of disease is a complex process that invovles numerous factors that apply to the pathogen, host, and environment. The following paper describes these factors. At this time, most of the information needed to create models that include disease is not available. However, it is recommended that transport regulations should be implemented that minimisize the risk of the exposure of exotic pathogens to wild fish.

INTRODUCTION

In recent years, the rearing of salmonid fishes in seawater netpens has become a large mariculture industry in several countries (e.g., Canada, Chile, Scotland, and Norway). With the growth of this new industry, there have been concerns about the impact that netpen farms may have on the coastal environment. As with most forms of intensive agriculture, infectious diseases are often a problem in these netpen farms. Therefore, in addition to concerns that these diseases pose to the industry, there is a concern about the potential impact that these diseases may have on coastal marine environments, especially on wild fishes. Models have been developed to assess the impact of aquaculture on coastal marine environments (Ibrekk et al. 1991; Silvert 1992). However, these models have considered the potential impact of diseases. Diseases of pen-reared fish pose a threat when 1) they are exotic diseases, 2) they represent an increase in the prevalence of enzootic diseases, and 3) their presence result in the release into the environment of drugs. The following paper addresses the potential threat of infectious diseases from salmonid seawater netpen operations to wild fish. Concerns about the use of antibiotics to control these diseases are dealt with by _______ (this issue).

Most cases of increased disease in wild fish populations related to aquaculture activities have occurred following deliberate release of hatchery-reared fish into new watersheds. For example, *Gyrodactylus salaris* has been introduced to Norway with the introduction of salmon from Baltic watersheds (Johnsen and Jensen 1991; Bakke et al. 1992). Heavy infections by the parasite have caused high mortality in Atlantic salmon smolts in drainages where the parasite has been introduced. There are also at least two cases that suggest introductions of a disease into wild fish from a fish farm or hatchery. Yoder (1972) concluded that the source of infections by the parasite *Myxobolus cerebralis*, the causative agent of whirling disease, in wild salmonids was a hatchery on the same river. Munro et al. (1976) reported increased prevalence of infectious pancreatic necrosis (IPN) virus in fish near a fish farm in Scotland.

Before farmed fish can be incriminated as the cause of disease in wild fish, the previous geographic distribution of the pathogen and prevalence of the disease in the wild population must be known. In the past, most research on salmonid diseases has been directed towards those occurring in the fresh water. With the rapid growth of mariculture, many apparently new diseases have been reported. Diseases that are thought to be unique to netpen farms may instead reflect diseases that occur in relatively low prevalence in wild fishes in the ocean. For example, netpen liver disease and plasmacytoid leukemia were first described in pen-reared fish, but we have recently found these diseases in ocean-caught salmon (Stephen et al. 1993).

Although it is difficult to determine if diseases of farmed fish have been transferred to wild fish, it is clear that pathogens from wild fish (both salmonids and non-salmonids) have had serious impacts on pen-reared fish. For example, wild salmonids are reservoirs of infection for the salmon louse, _Lepeophtheirus salmonis_, which is a serious problem in pen-reared Atlantic salmon (Pike 1989). Examples of non-salmonid reservoirs for netpen diseases in the marine environment include sea lice (_Caligus_ spp.) from a variety of fishes (Margolis et al. 1975), and spiny dogfish _Squalus acanthus_ for the eye tapeworm _Gilquinia squali_ (Kent et al. 1991). Wild salmon also act as a reservoir for bacterial diseases. Bacterial kidney disease (BKD), caused by _Renibacterium salmoninarum_, is the most serious disease of pen-reared Pacific salmon in British Columbia. In the mid-1980's wild brood stock were used as the source of eggs for the industry, and undoubtably introduced the bacterium, which is vertically transmitted through eggs (Evelyn 1993).

Factors Affecting the Transmission of Disease in Sea Water

To assess the potential increased impact that a farm disease may have on the wild population, the following factors should be considered. Factors that affect the development of disease can be viewed in three major interactive categories: the pathogen, the host, and the environment - exemplified by Snieszko's (1973) three intersecting circles (Fig. 1). In other words, the occurrence and severity of infectious disease is dependent on the status of the pathogen, host, and the environment. The latter is particularly important to fish because, being poikilothermic, the physiological state of fish is closely tied to water temperature.

The ability of a pathogen to cause morbidity or morality should not be the only concern. Certain relatively nonpathogenic parasites, such as Kudoa spp. (Myxosporea) are of concern because they may cause poor flesh quality and undesirable aesthetic changes (Whitaker and Kent 1991). In addition, some fish pathogens may infect humans or domestic animals. Lastly, the presence of certain pathogens in a fish population may impose restrictions on their sale or transport due to governmental regulations, even if the fish are not diseased.

The Pathogen

Several characteristics of pathogens from farmed fish are of importance for assessing the risk of increased disease to wild fish. Survival of the pathogen in sea water, ability of the pathogen to multiply in sea water, number of pathogens released from farmed fish, number of pathogens required to initiate an infection, virulence of the pathogen, and route of transmission are all important factors that effect the ability of the pathogen to cause disease in wild fish. Furthermore, to determine if a pathogen from a farmed fish causes increase in disease in a population of wild fish, a reasonable estimate of the previous geographic distribution and prevalence of the infection in the wild population should be available.

The ability of the pathogen to survive in sea water is a major component for assessing seawater transmission. This ability varies greatly between pathogens. Although considered freshwater viruses, IPN virus and the infectious hematopoietic necrosis (IHN) virus are capable of seawater survival (Toranzo and Hetrick 1982). In fact, the latter is capable of surviving much longer in sea water than fresh water (Winton et al. 1991). However, determination of the survival of pathogens in sea water is not a simple task because various environmental factors such as temperature, and organic load may affect survival (see Environment below).

Marine opportunistic pathogens are usually the most capable of being transmitted from farmed fish to wild fish because they are able to multiply in the marine environment outside of the fish host. However, caution must be exercised when implicating these pathogens as a threat to the wild populations. These pathogens may not be responsible for increase disease because they may already be prevalent in the wild fish (Håstein and Lindstad 1991), and only cause disease in the relatively crowded conditions of netpens. However, ubiquitous pathogens, such as Vibrio anguillarum, can cause disease in wild fish under the appropriate conditions. Therefore, these pathogens may still pose a threat to wild fish when farming activities result in a significant increases in the numbers of the pathogen in a given body of water.

The numbers of pathogens released from infected fish into the marine environment must also be considered. Certain bacteria and viruses are released into the water in high numbers from diseased fish, whereas others, such as histozoic parasites, may be released only after the fish has died and decomposed.

The route of transmission of a pathogen is another factor that should be considered. Some agents are transmitted directly through the water (e.g., most bacteria), whereas others utilize vectors or require intermediate hosts, such as tapeworms (Cestoda) and flukes (Digenea). For the latter, the numbers of potential intermediate hosts in the environment must also be considered.

The Environment

Physical oceanographic conditions play an important role in the transmissibility of the pathogen and the susceptibility of the host. The distance between wild fish and farmed fish, the density of wild fish, and the direction and velocity of water currents all greatly influence the likelihood of a viable pathogen coming in contact and infecting a wild fish.

In addition, water conditions affect the seawater survival of pathogens. Many fish pathogens a have relatively narrow temperature regime in which they can survive, multiply, and cause disease. The amount of dissolved organic material may also be very important. For example, in controlled laboratory conditions, *Renibacterium salmoninarum* survived much longer in sea water when a small amount of peptone was added (Paclibare et al. 1993). Biotic factors also influence the survival and transmission of pathogens. As already mentioned, invertebrates that act as vectors or intermediate hosts may be essential for transmission of heteroxenous pathogens. Conversely, invertebrates may consume pathogens, and thus reduce the possibility of transmission. Paclibare et al. (1993) demonstrated that mussels (*Mytilus edulis*) effectively removed *R. salmoninarum* from sea water, thus their presence on netpens may reduce transmission of the bacterium. Bacterial and viral antagonism inf uences the survival of pathogens, and Austin and Rayment (1985) found that the _R. salmoninarum_ could survive much longer in sterile water than unsterile water.

Wild fishes, both salmonids and no salmonids, should also be considered as biotic factors for disease transmission because they can also act as vectors, intermediate hosts or reservoir hosts. As already mentioned, wild salmonids are important reservoir hosts for a number of pathogens that are important to both wild and farmed fish. An example of an infection in which a fish is an intermediate host is with _Gilquinia squali_, in which teleosts such as whiting are normally the second intermediate host for the parasites (MacKenzie 1975; Kent et al. 1991).

THE HOST

The host's innate resistance, and physiological and immunological status play an important role in determining if an infection will be established and if disease will ensue. The following factors should be considered when assessing the threat posed by a pathogen for a population of wild fish: species susceptibility, strain susceptibility, age of the host, nutritional status, husbandry conditions and water conditions (see above), trauma (e.g., open lesions or abrasions that may facilitate entry of pathogens), sexual maturation, smoltification, preexisting infections and other co-factors, exposure to chemical agents (drugs used in treatment of diseases or anthropogenic contaminants), previous exposure and acquired immunity to the specific pathogen. In addition, unexplained "natural" variations in susceptibility between apparently identical individuals is an important factor.

It is well recognized that there is a wide difference in susceptibility to diseases between species of fish. Many important diseases of fishes have only been reported from salmonids. In addition, there is a great variability in the susceptibility to these diseases between species within the family Salmonidae. For example, Pacific salmon (*Oncorhynchus* spp.) are generally more susceptible to BKD than Atlantic salmon, whereas Atlantic salmon are more susceptible to furunculosis than Pacific salmon. This difference in susceptibility also occurs at the strain level. One of the best examples of differences in strain susceptibility is with *Ceratomyxa shasta*. Chinook salmon from enzootic waters are much more resistant than strains from watersheds where the parasite is absent (Zinn et al. 1977).

Age plays an important role in the susceptibility to disease. Many fish viral diseases, such as IHN and IPN, cause high mortality in fry. Older fish are generally more refractory, even if they have not been previously exposed.

The physiological state of fish during smoltification and sexual maturation may greatly increase the susceptibility to disease in general because these fish exhibit extremely elevated plasma cortisol levels, which is an indication of immunosuppression (Donaldson and Fagerlund 1968; Redding et al. 1984).

Nutrition may also control the severity of disease. Lall et al. (1985) reported that an increase in dietary iodine and fluorine was correlated with reduced prevalence of BKD.

Husbandry conditions (e.g., crowding) play a very important role in the transmission of infectious agents and development of disease. Crowded conditions may cause immunosuppression (Strange et al. 1978). In addition, the close proximity of the fish will enhance water-borne transmission of pathogens. Increased dissolved and suspended organics are often associated with crowded conditions, and can enhance the survival of pathogens in water. Crowded conditions may also increase the likelihood of skin abrasions and other surface lesions by fin nipping or scraping on tank/nets. Such abrasions could provide sites of invasion for pathogens (see Trauma below).

In addition to crowding, suboptimal husbandry conditions, such as too much light, excessive handling, improper water temperature or pH may all induce immunosuppression, and thus increase the likelihood of disease. Temperature may have a profound effect on the fish's immune system. At higher temperatures within a physiologically tolerated range, the onset of the immune response is usually faster and its magnitude is usually greater (Ellis 1982). This is particularly the case with the primary immune response (Avtalion at al. 1976). However, these higher temperature may also promote the proliferation of the pathogen in the water and in the fish.

Trauma resulting in skin abrasions or other surface lesions may enhance disease by providing a portal of entry for the pathogen. *Cytophaga* and *Flexibacter* spp. bacteria infect the surface of marine and freshwater fishes, and infections are often initiated at the site where the skin or fins have been damaged (Kent et al. 1988). In fresh water, the opportunistic fungi, such as Saprolegnia and related genera, commonly infect open lesions and necrotic tissue following trauma in freshwater fishes (Pickering and Willoughby 1982).

Infections can cause immunosuppression (Pickering and Christie 1981). There are many examples in which infection by one organism may provide a foot-hold for the establishment of another, at times more virulent, pathogen. For example, in coho salmon held in fresh water, infections by the erythrocytic inclusion body virus probably predisposes fish to infection by Cytophaga psychrophila (the cause of coldwater disease). The latter causes skin lesions that allow for Saprolegnia infections. Thus, it is common to find coho salmon in freshwater hatcheries infected with all three pathogens (Piacentini et al. 1989). Plasmacytoid leukemia of chinook salmon is probably caused by a retrovirus (Eaton and Kent 1992). However, BKD and a microsporidium Enterocytozoon salmonis often are found in fish with the leukemia and may be important co-factors that enhance the occurrence or severity of the leukemia disease (Kent et al. 1990; Kent and Dawe 1993).

Drug treatments and exposure to anthropogenic contamination may exacerbate infectious diseases. Rodsaether et al. (1977) reported that copper, which is often used as an external parasiticide in marine fish, exacerbated vibriosis in eels (Anguilla anguilla). Several pollutants, such as heavy metals and aromatic hydrocarbons, have been associated with increase in infectious disease problems in fish (Sinderman 1990; Kent and Fournie 1992; Overstreet 1992).

Lastly, in addition to all of these known factors, there is variation in susceptibility of fish within a population that is unexplained. This results in a phenomenon frequently observed in in vivo laboratory studies, called "the tank effect". In studies involving experimental infection, great differences in the prevalence of disease often occur between tanks in which conditions are apparently identical. This is exemplified in vaccine studies by Nikl et al. (1993). Two tanks holding the same number of apparently identical fish were exposed to the same inoculum of Aeromonas salmonicida, and one tank exhibited twice the mortality of the other.

In conclusion, assessing the risk of increased disease in wild fish due to aquaculture activities with any significant precision would be a very complicated task and would require much more information than is currently available. However, the potential introduction of an exotic pathogens that are virulent is probably the greatest risk that aquaculture poses to wild fish. Transport regulations should, therefore, be implemented to prevent the introduction of exotic pathogens into wild fish. To accomplish this specific task, many of factors outline above, such as host susceptibility, virulence, geographic distribution, survivability in sea water, and mode of transmission of the pathogen, should be understood to make rational regulatory decisions. In addition, the disease history of the fish to be transferred shoul be known and taken into account so that exotic diseases are not introduced with the fish.

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