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A review of potential impacts on wild salmon stocks from diseases attributed to farmed salmon operations

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Abstract

The scientific literature presents evidence that infectious disease agents have impacted on wild and cultured populations of both salmonid and non salmonid fish. Disease caused by an infectious agent is a complex interaction between the pathogen, the host and the environment. Our knowledge of two of these factors, the pathogen and the host, is increasing rapidly but the exact role of the environment in the disease interaction equation is still relatively unknown. Infectious diseases present in the Atlantic Provinces that have impacted on Atlantic salmon *(Salmo salar)* will be reviewed. The various steps required before a disease can be established in a wild population will be described. Finally, the measures available to the industry to minimise the potential impact of cultured salmon diseases on wild population will be summarised.

Résumé

Les publications scientifiques font état d'incidences qu'ont eu des agents pathogènes sur les populations sauvages et d'élevage de salmonidés et d'autres espèces de poisson. La maladie causée par un agent infectieux est une interaction complexe entre le pathogène, l'hôte et l'environnement. Nos connaissances de deux de ces facteurs, le pathogène et l'hôte, augmentent rapidement, mais le rôle exact de l'environnement au sein de l'interaction infectieuse demeure relativement inconnu. Les maladies infectieuses présentes dans les provinces de l'Atlantique et qui ont eu des incidences sur le saumon de l'Atlantique (*Salmo salar*) seront passées en revue. Les diverses étapes préalables à l'apparition d'une maladie dans une population sauvage seront décrites. Finalement, les mesures dont dispose l'industrie pour réduire l'incidence éventuelle des maladies du saumon d'élevage sur les population sauvages seront résumées.

Introduction

The potential impact of diseases on either wild or cultured fish has become an important issue for aquaculturists and managers whose role is to conserve wild fisheries. Currently, a contentious issue is the question of whether cultured fish can be a source of diseases that could affect wild populations. On the other hand aquaculturists are concerned about the converse situation, can wild fish transfer diseases to cultured animals? Our present knowledge does not allow for the precise quantification of the risks involved when assessing these possibilities. The identification of this particular problem has generated great interest and increased research in this new field is providing valuable data that will help formulate sound management decisions. A number of review papers on the potential impact of disease transfers between wild and cultured fish or vice versa have been published (Hastein and Lindstad, 1991; Brackett, 1991; McVicar et al. 1993; McVicar, 1997; Hedrick, 1998; Reno, 1998). The following paper will attempt to review the current state of our knowledge on this issue particularly focusing on the situation in the Maritimes Region.

Fish disease research has evolved rapidly in the last ten years principally in response to the need of a growing aquaculture industry worldwide. The economic importance of fish diseases on farmed fish has resulted in our increased knowledge of diseases in cultured fish compared to wild fish (Hedrick, 1998). The appearance, and in some cases the spread of disease in farmed fish is often the result of the high densities at which the fish are held and cultured fish offering the right conditions for an endemic pathogen to infect the population. In their natural environment fish are likely to be consumed by predators if weakened by a disease condition resulting in the loss of valuable data because proper samples to define the disease condition are not readily available (Kent and Fournie, 1992; McVicar et al. 1993; McVicar, 1997). In addition to sampling difficulties, there are several additional factors which limit our ability to effectively study diseases in wild fish (reviewed by McVicar, 1997). It must also be accepted that there has been a lack of effort in documenting diseases in wild fish, furthermore when instances were documented there was limited attempt to understand the "why" and "how" a specific disease can impact wild fish populations (Hedrick, 1998). The best evidence of infectious diseases in the wild are those which have resulted in massive mortalities, however, depending on the characteristic of the pathogen (is the pathogen highly virulent?) or the disease (is the disease chronic in nature?) there are likely several diseases or disease agents which are still unreported. Finally, it is crucial to have a good understanding of the dynamics of a disease and the pathogenicity of the disease agent before commenting on the possible impact that disease may have on a population, to date there are very few diseases on which such data exist.

Disease

Diseases are an integral part of the existence of all animals including cultured and wild fish and most people agree that diseases occur in natural populations and that pathogens can be present in the absence of diseases. Diseases can be caused by several factors including nutritional or genetic factors of the host, environmental factors and lastly infectious agents. Disease can be simply defined as a variation of the normal status of an animal, the equation Pathogen+Host+Environment=Disease, first proposed by Snieszko (1974), has been extensively used to illustrate the relationship between host, pathogen and its environment. All these factors must be investigated when attempting to describe a disease condition. Although this equation remains valid, recent studies indicate it may represent a less than accurate definition of diseases, it is too simple and does not take into account several additional contributing factors (Smith, 1997; Hedrick, 1998).

The first component of Sniesko's equation is the pathogen, its characteristics must be explored, including its obligate or facultative status, its virulence (ability to cause disease by defining the dose or the number of infectious agents required to cause disease) and how is the pathogen introduced (the route of infection and the duration of the infection). Additional information required include: is the pathogen able to induce a carrier state in fish, as is the case with furunculosis and infectious pancreatic necrosis. Finally the ability of the pathogen to remain viable and survive in the environment is also key to its successful transmission. All of the above represent essential elements needed to understand the dynamics of a disease

The host must also be investigated, is the host susceptible to a particular disease. This is a key factor since some pathogens can infect only a limited number of fish species; for example, IHNV mainly affects sockeye salmon (*Oncorhynchus nerka*), while current information suggests that ISAV infects only Atlantic salmon (*Salmo salar*). The age and sex of the host species are also relevant, some age groups are highly susceptible to an infection while other age groups may not be e.g. infectious pancreatic necrosis virus (IPNV) and infectious haematopoietic necrosis virus (IHNV) usually affect young fish (Wolf, 1988). The overall health status of the host population can also influence the successful transmission of a disease. Animals that may be stressed by a variety of extrinsic factors may be more susceptible to diseases especially during spawning and smolting periods (reviewed by Pickering, 1997). Finally the nutritional status of the population can also change or affect their susceptibility to diseases. This factor is poorly understood in relation to wild fish but laboratory work has generated interesting results on the effect of nutrients on disease susceptibility of fish to certain diseases in particular furunculosis (see Olivier, 1997).

The environment represents the last factor needed to be understood and it remains the least defined of all. Water quality including dissolved oxygen, temperature and physicochemical composition, as well as fish densities can all influence disease incidences in hatcheries and farms. In summary diseases are the result of the complex interactions of variables of the host, the pathogen and the environment. Only when a better understanding of these variables is obtained will we be in a position to recommend more meaningful management practices.

Diseases impacting wild non-salmonid fish

The best documented epizootics of a fish disease affecting wild marine fish are those of the pathogenic fungus *Ichthyophonus hoferi* in Atlantic herring (*Clupea harengus*) on the North American east coast. It is one of the rare instances where a disease of define aetiology has severely impacted wild stocks of a marine fish species (McVicar, 1982; Sinderman, 1990). Other fish pathogens have also impacted wild fish stocks during specific epizootics but their effect at the population level is difficult to establish, in most cases only a regional or local effect has been documented. The bacterial pathogen *Pasteurella piscicida* has been isolated from mass mortalities of striped bass (*Morone saxatilis*) in Chesapeake Bay, USA (Snieszko, 1964). This pathogen is an emerging problem in both Europe and Japan where it affects a variety of cultured and wild marine fish species (Austin, 1993). In 1995 an extraordinary epizootic affected schools of pilchards (*Sardinops sagax neopilchardus*) in Australia (Whittington et al., 1997; Hyatt et al., 1997). Investigations of this particular epizootic revealed that a herpesvirus was consistently present in gills of affected fish only, and therefore as been proposed as the aetiological agent of the mortality.

The virus causing viral haemorrhagic septicaemia (VHS), an important disease of salmonids, was initially thought to be a freshwater fish pathogen primarily affecting farmed rainbow trout (Wolf, 1988). During the last ten years, the epizootiology of this disease has changed dramatically, and is still evolving. VHS is now considered to be present in several marine fish species in Europe as it has been isolated from Atlantic herring (*Clupea harengus*) (Dixon et al. 1997), Atlantic cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) (Dixon et al., 1997) strongly suggesting marine reservoirs of the virus. VHS was recently isolated from the West Coast of North America, in spawning wild Pacific salmon. The first recording of VHS in North America was initially thought to be the result of the introduction of VHSV from Europe. After several years of research, it is clear that the virus was not introduced but was likely present in marine reservoirs, a situation similar to VHS in Europe. The virus is endemic in populations of Pacific herring (*Clupea pallasi*) and Pacific cod (*Gadus macrocephalus*) on the west coast of North America. Based on molecular characterisation of the isolates, it was also demonstrated that the North American strain of VHS is different than the European strain (Meyers and Winton, 1995). These recent results confirm the wide distribution of VHS in the marine environment and have led to speculation that the original isolate affecting rainbow trout in freshwater in Europe may have been introduced from marine fish used to feed trout in the early days of aquaculture prior to the era of pasteurisation (Dixon et al., 1997).

In the Maritimes Region two additional disease agents were also found in wild populations of Atlantic tomcod (*Gadus microgadus*) and American eels (*Anguilla rostrata*). The causative agents are atypical strains of *Aeromonas salmonicida*; in both host species the disease is characterised by the appearance of cutaneous lesions similar to those caused by atypical strains of *A. salmonicida* in non salmonid hosts including goldfish (*Carassius auratus*) and carp (*Cyprinus carpio*). This ulcerative condition has been recognised in several drainage basins of the Maritimes Region but the impact of these disease agents on wild populations of tomcod and eels remains unclear. The same is true for several other atypical strains of *A. salmonicida* found in several marine and freshwater species, either wild or cultured; their real impact is unknown (Bernoth, 1997).

Diseases impacting wild salmonid fish

Regarding salmonid species, historical data indicate that epizootics in wild salmonids were happening in fresh water as early as the turn of the century. In England there are reports of an epizootic of ulcerative dermal necrosis (UDN) which is caused by a still unknown infectious agent. The first epizootic was reported at the turn of the century and the second one in the 1960s (reviewed by Bucke, 1993). Records of disease incidence in wild fish before the presence of cultured fish strongly indicates that diseases have been present in wild fish for a long time and that initially diseases of wild fish were transferred to cultured fish and not vice versa (Hastein and Lindstad, 1991).

There are three important documented examples where fish diseases have severely impacted wild salmonid populations. Furunculosis (typical *A. salmonicida*) was introduced in Norway in the mid 80s following the importation of Atlantic salmon smolts from Scotland; the disease was not controlled and eventually spread throughout the salmon industry. The disease was transferred via escapees to wild populations of Atlantic salmon in several rivers and has impacted wild stocks significantly (Johnsen and Jensen, 1994). Whirling disease caused by the parasite *Myxobolus cerebralis*, has spread to several wild trout populations in several US states and in some cases the impact of the disease in wild trout populations has been very severe (Nehring, 1996). Finally the skin parasite *Gyrodactylus salaris* first recognised in Sweden as early as 1957 has spread to Norway and severely impacted Atlantic salmon smolts in Norwegian rivers (Johnsen and Jensen, 1991).

Interestingly the former three examples confirm the severe impact fish disease can have on wild stocks, however, in these instances the introduction and further spread of the disease agent was the result of movement or transfer of live fish. On the west coast of North America, disease agents including the typical strain of *Aeromonas salmonicida* and *Renibacterium salmoninarum* are also present in wild populations of Pacific salmon. These bacterial pathogens have been documented to have severe impacts on cultured fish including Atlantic salmon; as for their potential effect on wild populations, it remains unclear (Stephen and Iwama, 1997).

Infectious haematopoietic necrosis (IHN) is a viral disease mainly affecting sockeye salmon (*Oncorhynchus nerka*) on the West Coast of North America, it is interesting to note that all documented IHN epizootics in wild populations have occurred in sockeye or kokanee salmon. Nevertheless the sockeye and kokanee populations remain viable in British Columbia and Alaska where IHNV is endemic and IHN epizootics have regularly occurred in these populations (LaPatra, 1998). The virus causing infectious pancreatic necrosis (IPNV) has been found in wild populations of Atlantic salmon and rainbow trout in Europe and Canada (Bucke, 1993, McVicar et al. 1993) but there is no evidence that this disease agent impacts wild fish.

Diseases impacting salmonids in the Maritimes region

In the Maritimes region, we have extensive knowledge of some diseases in wild populations of Atlantic salmon in some drainage basins (reviewed by A. M. Mackinnon, see paper 10). The Maritimes region is free of all the Notifiable disease listed in the OIE Manual including the important viral diseases VHS, IHN, OMV (OIE, 1997). Bacterial kidney disease, furunculosis, vibriosis, sea lice and ISA are the main diseases affecting the Maritime aquaculture industry. In wild Atlantic salmon, two significant disease agents are known to be present in the Maritimes namely *Aeromonas salmonicida* (Olivier 1992) and *Renibacterium salmoninarum* (Paterson, 1979). *A. salmonicida* has been detected in two major drainage basins in New Brunswick since early 1970s, the St-John and Restigouche Rivers. In 1997, furunculosis was reported from the first time in the Miramichi River. In these three drainage basins mortalities due to the disease have occurred but it is difficult to establish what impact, if any, the disease has had on the wild populations of these rivers. Although ISA has severely affected the Atlantic salmon industry since its first appearance in 1996, extensive testing of wild salmonids and non-salmonid fish for the presence of ISA has yielded negative results so far. The potential impact of ISA on wild salmonids is perceived to be significant but there is no evidence from Norway (where the disease was first recognised in 1984) nor from the Maritimes Region that ISA is impacting wild Atlantic salmon.

Regulations

The highest risk to a wild Atlantic salmon population would be the introduction of an exotic disease (a disease never found previously in a specific region) into an area where the feral population would not have any resistance against the pathogen. International and national regulations exist for the specific purpose of avoiding such a scenario, specifically the Office International des Epizooties (OIE) has published the International Aquatic Animal Health Code providing a standardised approach in order to minimise the risk of disease transfer through trade of fish and fish products. In Canada the Fish Health Protection Regulations promulgated in 1977 under the Fisheries Act serve as our National standard to minimise the risk of disease transfer associated with interprovincial transfer of fish or fish products. Minor amendments to the FHPR were instituted in 1987, 1992 and 1997. The FHPR are under revision and major amendments should be introduced and implemented in 2000, these will include new items: zoning concept supported by a surveillance program, quality assurance quality control (QA/QC) program and a compensation program. In addition to the international and national guidelines, the Maritimes Region uses Regional Fish Health Guidelines to control the transfer of salmonids intraprovincially; salmonids must be free of clinical signs of BKD and other culturable bacterial fish pathogens before they can be transferred between watersheds.

Reducing risk factors in wild or cultured fish.

For fish farmers, there are several approaches available to control and manage diseases. The first one is avoidance; this is possible through strict regulation of fish movement already discussed above. Other approaches include "culling" or "depopulation", which can be used in specific cases following the introduction of an exotic disease into a new area; however from the industry's perspective this is unacceptable unless a compensation program is in place. In Scotland, based on EEC rules regulatory agencies are using eradication to control ISA following its identification in 1998 (A. MacVicar, pers. comm.). In New Brunswick where ISA was confirmed in 1997 (but was likely present as early as 1996 and termed haemorrhagic kidney syndrome (HKS)) the ISAV control program advocated by the New Brunswick Fish Health Technical Committee involves increased surveillance and depopulation at positive cages showing increased mortalities due to ISAV. Total eradication of ISA in New Brunswick was not seen as an option because of the hydrography of the Bay of Fundy and is also unrealistic because ISA had been present for at least one year before its identity was confirmed. In some cases, for example when a pathogen is endemic in an area, other measures must be taken; if at all possible vaccination is the preferred choice. Over the last few years, enormous advances have been made in this field and there are effective vaccines against many major fish pathogens including *Aeromonas salmonicida* (furunculosis), *Vibrio Anguillarum and V. salmonicida* (vibriosis).

Finally, additional measures that could be implemented by the industry include mandatory site fallowing, the use of single year class growout sites and a delineation of minimum distances between sites (reviewed by Stewart, 1998). In addition, the establishment of comprehensive fish health programs for the industry is highly recommended.

In contrast, the control of diseases in wild populations is usually not effective and fisheries managers are left with few options to deal with these conditions. There are instances where a comprehensive eradication program has been successful in eradicating a specific disease, for example VHS in Denmark (see Olesen and Korsholm, 1997). However, in most cases eradication of diseases in wild populations is difficult, for example in Alaska, where attempts to free sockeye stocks of IHNV were unsuccessful even after severe control measures had been in place for several years (Meyers, 1998).

How are diseases introduced or spread

Furthermore lets not forget that as stated previously the presence of a pathogen in a fish is not necessarily indicative of a disease condition. In order for a disease to spread from either a cultured fish to wild fish or vice versa, certain criteria must be fulfilled, they include:

- the source fish must contain the pathogen
- the pathogen must remain present
- the water must contain susceptible host
- the pathogen must survive in the environment
- the pathogen must be exposed to a susceptible host by a route that allows infection

- the pathogen must be in biologically significant numbers to initiate infection in the host
- the infection must spread to other hosts

The above criteria clearly indicate that the presence of an infectious agent in any specific host should not be directly correlated with disease transfers to other susceptible animals. Unless all of the above criteria are met, the introduction or spread of a disease agent will not occur.

Conclusions

In rare cases, evidence is presented that infectious agents can have an impact on wild non-salmonid fish populations, although the exact impact of most diseases on wild stocks is difficult to adequately quantify. These events are rare and could be cyclic. Respecting salmonids, there are again cases where diseases have been found in wild fish where an impact on the stocks has been demonstrated. Although disease interaction between wild and cultured fish do occur (Brackett, 1991, McVicar, 1997) there is no documented evidence to substantiate the hypothesis that wild Atlantic salmon populations may be declining in the Maritimes Region as a result of the spread of diseases originating from farmed fish.

New advances in the field of fish diseases, increased surveys targeting specifically wild fish to determine their fish health status as exemplified by the work performed by several research groups, will broaden our knowledge base of diseases of wild fish, which was until recently heavily biased towards cultured fish (McVicar et al. 1993; Meyers and Winton, 1995; Dixon et al., 1997; Kent et al., 1998). The Increased use and adaptation of mathematical models to study the spread of diseases in wild fish population should help our quest to elucidate the relationship, if any, between diseases in wild versus cultured fish (Reno, 1998).

This report does not attempt to explain how pathogens are introduced into a population, however, it is crucial to remember that most fish pathogens were probably present in wild fish prior to the development of the aquaculture industry; what happened is that aquaculture produced conditions which may have been more conducive to disease development in a closed crowded environment. The transmission of disease from wild fish to cultured fish and vice versa, as stated previously, has occurred and will continue to do so but the impact of these transfers on either wild or cultured fish cannot be easily quantified. Data exists to support both avenues, the major problem is that aquaculturists and wild fish defenders see the route of transmission as one way only, their way. There is a need to investigate the situation, this will allow us not cast the blame but effectively make sound decisions acceptable to both parties. Increased knowledge of fish diseases will eventually benefit all concerned.

Recommendations

There is an urgent need for increased disease surveillance in wild fish. Disease surveillance should include marine non-salmonid species because recent data strongly suggest that marine non salmonid fish can be reservoirs of several important fish pathogens. However, improved diagnostic methods are also urgently needed in order to increase our capability of detection of several fish pathogens.

Governments and industry should collaborate to institute a comprehensive fish health program aimed at limiting disease impacts on farms. Such a program will benefit all by reducing the incidence of diseases at the farm level (economically significant for the farmer) and reducing the risk of disease transfer from cultured to wild fish.

It is time to change our basic philosophy on diseases, we should investigate how to keep fish healthy and not necessarily focus so much on why the fish are sick!

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