Salmon Aquaculture Dialogue

Working Group Report on Salmon Disease

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The goal of the Dialogue is to credibly develop and support the implementation of measurable, performance-based standards that minimize or eliminate the key negative environmental and social impacts of salmon farming, while permitting the industry to remain economically viable

The Salmon Aquaculture Dialogue focuses their research and standard development on seven key areas of impact of salmon production including: social; feed; disease; salmon escapes; chemical inputs; benthic impacts and siting; and, nutrient loading and carrying capacity.

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More information on the Salmon Aquaculture Dialogue is available at: http://www.worldwildlife.org/salmondialogue

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Executive Summary

The concerns related to farmed salmon diseases and their potential effects on wild fish and ecosystems are complex and contentious. Our report identifies critical gaps in the scientific understanding of the dynamics of health in wild fish populations and how that dynamic is shaped by interactions with salmon farming, all of which are shaped by ecological, management and regulatory factors. Different disease agents involving different host species in different environments interact with other natural (including human) factors in a complex network of disease interactions. These interactions are constantly changing and have only rarely been studied in sufficient depth or breadth to result in science-based risk assessment and management. We conclude that it is not currently possible to resolve the debate about diseases from aquaculture affecting marine ecosystems due to important gaps in understanding of key ecological, epidemiological and pathological features of salmon diseases. A generic risk statement cannot encompass the diversity of diseases and species associated with salmon farm ecosystems. However, at the local level, seeking to reduce disease on salmon farms provides the dual benefit of increased farm productivity and minimizing potential impacts on wild fish populations.

The purpose of this report is to present information relevant to the identification of environmental and social performance indicators leading to reduction or elimination of disease impacts on wild salmon populations by salmon farming, with the eventual goal of formulating standards of practice. We provide background information in chapter one to give readers a shared understanding of fundamental principles of disease impacts, disease transmission and the relationships between health and disease. In chapters two to five, we examine the evidence or experience available with which to identify best management practices to consider when developing on-farm standards. These chapters emphasize steps that might be taken to reduce the risk of disease transmission between farms and between farmed and wild fish. Using examples based on specific disease agents, these sections address generic methods that could be applied to reduce risk, even in the absence of disease specific risk assessments. Chapter 6 summarizes key uncertainties regarding wild-farmed fish interactions, presents strengths and weaknesses in areas of risk management and provides recommendations for addressing knowledge gaps.

This report emphasizes the marine portion of the salmon production cycle due to the fact that most of the concerns about disease transfer to wild fish are focused on the ocean rearing of salmon in farms. The report is focused on infectious and parasitic diseases because they have been the greatest source of scrutiny and concern. However, there are many non-pathogen factors influencing the health of farmed and wild fish such as environmental quality, genetics, and nutrition, and at least some of the non-infectious disease hazards, such as those linked to the use of antibiotics, are directly or indirectly considered in other reports of the Salmon Aquaculture Dialogue.

The fundamental way to reduce risk arising from infectious and parasitic diseases transferring to wild fish from salmon farms is to reduce exposure of wild fish to disease-causing agents. However, identification of how important exposure to pathogens from farm sources, relative to natural exposure to pathogens from wild sources, is rarely conclusive. There are many policies and procedures at regional and local levels aimed at creating or enhancing barriers to the transfer of pathogens between farmed salmon and wild fish, including farm siting and stocking regulations that separate populations by location and age, and biosecurity measures blocking inadvertent movement of pathogens. However, none of these methods provide complete barriers. Disease control practices, such as vaccination, nutritional management and optimal husbandry, were largely developed to enhance the productivity of farmed fish. Actions that reduce the probability of farmed fish contracting an infection, or experiencing clinical manifestations (i.e. disease) due to that infection, will reduce the prevalence of diseases on farms and the spread of disease between farms which in turn decreases the probability of transmission to wild fish.

In some jurisdictions, farm siting regulations incorporate goals of reducing or preventing farmed-to-wild fish exchange of disease agents by enhancing physical distance between salmon farms and ecologically sensitive areas (e.g. large smolt populations out-migrating from rivers). As disease is a natural occurrence in both farm and wild populations, a major challenge in identifying best practices is quantifying the minimum distance between a farm and a sensitive wild species (or lifestage) that reduces the probability of disease transmission below the probability of the wild population contracting the disease from another natural source. In general, information on the movements of fish pathogens in the marine environment, the transmission ecology affecting wild and farmed fish, and the viability of pathogens shed in the marine environment is usually sparse or lacking. This makes selecting a single standard for siting, applicable over multiple jurisdictions, problematic. However, effort to investigate these factors and refine the standards for farm site selection within different regions is important for policy decisions protecting wild populations.

Cage culture remains the most common form of salmon containment for marine farming. Current cage designs allow the release of fish excrement and the free movement of water, small wild fish, and other marine organisms into and out of cages, providing potential routes for pathogens to move beyond the physical limits of the enclosed population. Land-based or closed containment rearing has been proposed as more complete barriers that would greatly reduce or prevent waterborne movement of pathogens. Although this barrier may be a useful method to reduce pathogen exchange in both directions, a review of the cost effectiveness, impacts on farmed fish health and overall feasibility of this approach is beyond the scope of this report.

Biosecurity remains a cornerstone of disease risk reduction. Many companies and governments prescribe specific actions taken to prevent the movement of disease-causing organisms due to the movement of fish, equipment, or personnel on or off fish farms. The principles of sound biosecurity are adapted from health management of terrestrial farms and usually do not require existing knowledge of specific diseases. International, national, regional, and company biosecurity protocols and standards are commonplace, including equipment disinfection practices, programs for disease prevention (e.g. vaccination, nutritional management, avoidance of stressful handling events), early detection of diseases through surveillance, ready access to disease investigation services, and response plans to treat or manage emerging and endemic diseases. The sophistication of these programs rivals and sometimes exceeds many terrestrial agriculture systems. However, these standards are only as effective as the people implementing them. Breaches in biosecurity are particularly common when there is no known disease threat. Some companies use third-party sources to evaluate and audit their procedures while in other cases, government audits ensure comprehensive health management principles and practices are applied. Unfortunately, little research has been directed towards creating the data needed to construct evidence-based herd health programs, making it challenging to specify and prioritize actions that are necessary and effective at reducing risks to acceptable levels. Moreover, variations in local environments, definitions of acceptable disease risk, the diversity of disease agents, and available farm infrastructure prevent a “one-size fits all” approach to health management planning.

In addition to creating barriers limiting the spread of infection, the probability of exposure of wild fish to pathogens from farmed fish may be reduced by minimizing clinical disease in farmed fish. In the past, farmers often relied on treatments (e.g. antibiotics) and minimizing disturbance of affected populations to reduce the magnitude or duration of a disease outbreak. More recently, significant attention has been focused on the development of management methods to prevent disease outbreaks and manage them more effectively through interventions targeted at pre-clinical stages of disease. Through extensive use of vaccines, particularly for bacterial diseases, disease prevention success has greatly reduced the need for antibiotics in salmon farming over the past decade or more. There remain, however, some important diseases of farmed salmon for which effective vaccines are not available. Even effective vaccines depend on optimal rearing conditions, host condition, and environmental quality to prevent being overwhelmed by greater loading of pathogens in the vicinity of healthy animals or frequent contacts between infected and naïve individuals. It is for this reason that environmental management and husbandry are crucial components of sound salmon health management practices and form part of the expectations of licensing bodies in some jurisdictions. The use of rigorous clinical field trials to demonstrate the effectiveness of these disease interventions is a relatively new phenomenon in salmon farming. Although tank-based experiments were used historically to evaluate methods for disease control, these fail to reflect the ‘real-world’ application of disease management methods. Clinical field trials are being increasingly used, but typically restricted to the evaluation of antibiotics and vaccines and concerned almost exclusively with the risks and benefits to the farmed fish only. Thus, their beneficial effects for reducing risk to wild fish remain poorly evaluated.

Assessment of environmental impact pre-supposes knowledge about the current state. This report highlights the significant deficiencies in our understanding of the epidemiology of disease in wild fish in the absence of fish farms, about the frequency, magnitude and significance of movement of pathogens between wild and farmed fish, and about the effectiveness of various interventions to prevent or mitigate disease risk to the environment. Establishing the presence, or magnitude, of impacts of salmon diseases is seriously challenged by our inability to disaggregate the impacts of pathogens and parasites on the ecology (or its components) from the other stressors facing marine biota. This challenge is even greater given the unknowns regarding the ecology of many marine species in general and more specifically on the effects of natural levels of disease on the fitness, abundance and distribution of marine wildlife. Evidence in the scientific literature about the additive effects on wild fish of diseases originating from, or magnified by, salmon farms is contradictory and inconclusive. Even in the absence of fish farms, we lack the knowledge to forecast the health of wild fish populations and we have a poor understanding of the cyclical or random components of marine diseases that are changing over time, especially with the potential influence of climate change. However, lack of evidence must not be interpreted as evidence for the absence of risk.

The presence of uncertainty is not unique to disease interactions in salmon farming, but it frequently plagues environmental impact assessments in general. We suggest that most salmon farm disease issues do not have sufficient certainty about the probability or magnitude of hazards to facilitate classic risk assessment or sensitivity analysis. Although uncertainty can be partially addressed by employing wide safety margins for risk estimates, the lack of consensus on the definition of acceptable levels of risk reduction achieved through disease control methods complicates science-based selection of acceptably wide safety-margins.

While we conclude that the general sophistication and effectiveness of fish health management has progressed significantly, the influence on reducing risk of disease transmission to wild marine organisms is difficult, sometimes impossible, to quantify. Multiple strategies are practiced by farms to control infection and these actions can reduce, but not eliminate, the probability of exposure of wild fish to disease causing agents. Identification of precise indices reflecting reliable and meaningful fish health outcomes across countries and companies will need to be adaptable to the variability in marine ecosystems and community expectations. A science-based approach will not, by itself, define what is acceptable with respect to disease transmission probabilities. Exploring methods for uncertainty analysis, qualitative risk assessment and multi-criteria risk analysis capable of combining quantitative data, uncertainty and social values may be a way forward to allow for more rigorous and objective assessments of the impacts of fish diseases until critical scientific uncertainties are resolved.

Although evidence supporting new disease introductions by salmon farming or serious consequences arising in wild populations from such events is rare, disease exchange between farmed and wild salmon continues to be the subject of significant scientific and public debate. It is reasonable to conclude that advocacy for a zero probability of transmission of disease between farmed and wild is also advocacy for an end to any farming that exchanges untreated water, as is the case with cage culture of salmon. Non-zero probability of disease transmission does not imply that there exists any risk to wild fish greater than levels found in nature in the absence of any farms. However, we believe that advocating for required comprehensive infection control on farms is reasonable and can result in reducing risk for wild fish to levels similar (or below) the background level of risk. Furthermore, we believe that selecting, managing and enforcing infection control practices will require research to identify meaningful and reliable indices of effectiveness as well as validating the effectiveness of health management from an ecosystem perspective. Most challenging will be developing political and social consensus on the targets for disease risk reduction given the prevailing uncertainties.

Comments regarding the combined approach to General Disease and Sea Lice reports

The term "disease" captures a wide array of physical, physiological and population abnormalities. An exhaustive review of the state of knowledge on fish disease would require an evaluation of multiple disciplines, ranging from molecular biology to pathology to epidemiology as well as the consideration of a range of relevant species. Once the issues of how disease might affect conservation goals or ecosystem functions are added, additional information on ecology and the means to manage disease impacts, including legislation, open up for review. The breadth of such a suite of information is daunting. It is further complicated by the many contradictory findings and important uncertainties that exist around the issue of diseases of farmed salmon and their potential environmental impacts.

The *General Disease* Technical Working Group (TWG) consisted of 5 scientists from 5 different locations (Hammell from Eastern Canada, Stephen from Western Canada, Evensen from Norway, Bricknell from Scotland then Maine, Bustos from Chile with further contributions from Enriquez) and the *Sea Lice* TWG consisted of 4 more scientists (Revie from Scotland then Eastern Canada, Dill from Western Canada, Finstad from Norway, Todd from Scotland). The two groups initially met jointly to outline the breadth of the report and to further define the approach to evaluating sea lice issues in depth. The decision to cover general disease broadly and sea lice as the in-depth case study was the group's attempt to address the seemingly impossible task of adequately describing the state of knowledge and research gaps for an area of research that spans many different disciplines and diseases across many areas of the world in which salmon is farmed. The Sea Lice report adopted the same basic outline except for specific headings that were irrelevant. The final chapter 6 (*Addressing Unknowns in Disease Risk Management*) of the General Disease Report contains comments contributed by both groups.

Our approach was based on answering the questions of 1) what is the risk of disease transfer from farmed to wild salmon (i.e. should we be concerned)? 2) can salmon farms avoid disease in their fish? 3) assuming that farms cannot avoid disease, can salmon farms adequately reduce the level of disease in their fish to a level that would reduce the risk of transfer to wild salmon? And lastly, 4) what are the gaps in knowledge regarding the risk of disease in farmed and wild fish when considered separately and when considered in each other's presence? We then decided that there were 2 important reasons to take sea lice as the one disease to consider in greater detail using the same risk based approach: 1) sea lice issue has had a great deal of attention in peer-reviewed literature paid to ecology and the risk of interactions between farmed salmon and the environment, and 2) sea lice was identified by the Steering Committee (Salmon Aquaculture Dialogue) as a particular issue for focus. Essentially, the reports were generated as stand-alone reports but our combined approach provides breadth (general disease) and depth (sea lice) on which establishment of measurable standards can be discussed in the next stages of the process.

Chapter 1: Core Concepts Related to Disease Risk

1.1 Introduction

The goal of modern salmon farming is healthy fish production. Ideally, this means the fish remain healthy during the production cycle, they result in healthy and safe food products, the farms economic productivity is viable and the supporting environment for the farm remains sustainable. Such a goal becomes very dependent on what one means by “healthy.” The measures of health for the fish are clearly not all the same as for the supporting environment. From a fish perspective, health is hard to disentangle from the idea of welfare. Healthy fish have access to the needs for daily living, can cope with external stressors and meet our expectations for production. Animal welfare, as the term is typically used in food production systems, is concerned with the provision of the conditions and resources for an animal to fulfill these criteria for health. The bulk of the work of aquaculture health managers is, therefore, aimed at ensuring the welfare of the salmon under their care through proper husbandry. However, most of the attention and debate around salmon health focuses on the treatment and prevention of disease. This is for 3 main reasons. First, the history of salmon health research has emphasized the study of infectious disease agents and pathology. Second, infectious diseases remain a significant production limiting factor and economic cost to the industry. Third, there is acute public concern that infectious diseases occurring on salmon farms can be transmitted to and impact wild fish. For these reasons, much of this report will focus on diseases. However, the authors wish to emphasize that there are many other factors that contribute to the health of fish than the absence of disease and that future efforts to promote the sustainability of aquaculture operation must be built on a firm foundation of health and welfare promotion and protection and not simply on disease treatment and prevention.

Few issues associated with salmon farming are as a controversial or inspire as passionate debate as disease. The majority of the debate is associated with the marine phase of the production cycle where the farmed salmon are separated from wild marine life by a permeable net cage that allows the potential movement of disease causing agents back and forth between the farmed salmon and the sea around them. Salmon farm related diseases have features that can result in a high public risk perception. Such features include (1) the cause of the problem, called a hazard, is invisible to the naked eye (like a virus or bacteria); (2) the hazard is new, previously unknown or unfamiliar; (3) there is inequitable sharing of risk and benefits wherein one group tends to benefit more, while others bear more of the impact of the hazards; (4) there is the potential for severe impacts and (5) options for reducing or avoiding the risk are out of the control of the individual concerned about the risk.

Prevailing uncertainties that limit our ability to predict local risks from diseases can also contribute to the high risk perceptions of disease. Much of what we know about salmon diseases is relatively new and there remain many gaps in what we know about how diseases affect wild marine life. Until about 50 years ago, most work on fish diseases focused on describing the parasite or bacterium found in a sick fish, with little attention to the fish itself. In the 1960's fish began being used as sentinels of pollution. Interest in the pathology of cancer or other diseases emerged as we tried to understand the effects of marine pollution. However, the focus was largely on the affected individual fish and not on the role of disease in ecosystems. Although aquaculture is an ancient practice, it was not until it moved from a subsistence or smallholder farming to a corporate food production model in the past 30 years that researchers turned their attention to how diseases affects fish health. Even this work has largely dealt with the effects of disease on individual fish most often studied in artificial rearing conditions and exposed to diseases agents at unnatural levels. Only recently has knowledge of how diseases 'work" in free-ranging fishes or how disease-causing agents move between different groups of fish begun to emerge. Because of this, it is challenging to resolve debates about the risk of salmon farm diseases for many of the pathogens and parasites of concern based on proven scientific facts.

The objective of this report is to provide the reader with an overview of the main variables governing potential diseases risks associated with salmon farming. We will attempt to summarize the current science, practices and policies that can affect how diseases causing agents related to salmon farming might impact free-ranging or non-farmed species and how those impacts may be prevented or mitigated.

1.2 Focus on infectious and parasitic diseases

This report will deal exclusively with diseases associated with living organisms such as viruses, bacteria and parasites. Table 1 provides an overview of the major infectious and parasitic diseases of farmed salmon and their known distribution around the world. We will focus largely on the marine phase of salmon farming as this provides the greatest interface between wild marine life, the marine environment and farmed salmon. The decision to restrict this report to infectious diseases does not imply that there are not other potential health issues related to non-infectious diseases or that there are no health concerns linked to drug or chemical use by salmon farms. Rather, this decision reflects the fact that the bulk of debate around salmon farms and disease revolves around the movement of infectious agents between farmed and wild fishes.

There are 3 phases of an infectious disease. First, the pathogen[1] must find a susceptible host and attach onto or invade it somehow. This is termed colonization and is the phase where the pathogen can be found in or on the fish, but it has not yet invaded or established itself in a manner that evokes a strong host response. The second phase, known as infection, occurs once the colonizing agent invades and multiplies within the host and begins to cause host injury. This response is typically due to activation of host defenses such as the production of more mucus on skin or gills, the production of local signaling molecules that attract inflammatory cells and also result in increase blood flow in the damaged area. Later in this response there is a production of antibodies or the activation of specific immune cells. A fish may be capable of ridding itself of a pathogen at the stages of colonization or early infection without demonstrating any obvious adverse effects. If it cannot rid itself of an established infection, the fish moves to the third phase; clinical manifestation of disease.

A disease state results once a pathogen and/or the host's response to the pathogen causes an adverse effect in physiological functions, behavior or the integrity of organs of the fish. There are 3 outcomes to a disease. First, the fish's immune function may limit replication and eliminate the invading pathogen, resulting in recovery from the disease before the fish shows obvious signs of illness. This is termed sub-clinical diseases. Such diseases are not necessarily benign because sub-clinical disease can affect factors such as growth rate, feed conversion, ability to evade predators and ability to meet full reproductive potential. The second form of disease is clinical illness where a fish shows observable signs that it is sick. A fish can

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[1] Hereon, the term pathogen will be used to describe any living organism, or virus, able to cause diseases. Where it is important to distinguish parasites from other pathogens, both terms will be used.

recover from a sub-clinical or clinical infection; sometimes with the aid of drugs or chemicals, sometimes without such veterinary support. While still a young science as compared to others forms of veterinary medicine, the clinical treatment of fish diseases has made remarkable strides in the past two decades. Often, however, once clinical signs are seen in fish, the animal is significantly ill and near death. Yet another outcome of a sub-clinical or clinical disease is that surviving fish will become persistently infected with the pathogen. In the persistent stage affected fish show no clinical signs of disease but carry and shed the pathogen to the environment. For some disease such individuals may be important sources of pathogen spread. The third potential outcome of disease is death. Here the fish is unable to combat the effects of the pathogens and/or cope with adverse effects of the body's attempt to rid itself of infection. Because most fish diseases research has been conducted in laboratories under artificial conditions and because most diagnostic tests used on fish require a fish to be killed to collect samples, sub-clinical effects of diseases have been rarely studied. There has been the belief in the past that "an infected fish is a sick fish and a sick fish is a dead fish" because clinical illness often does not appear until the fish is near death, which is particularly true in wild fish where veterinary intervention is virtually impossible. Today, such a conclusion is premature until new diagnostic methods can be developed to measure and monitor fish for all manifestations of disease and the progression from colonization to final outcome can be studied under natural conditions.

Diseases can be discussed in terms of the individual, the population or the community. The vast majority of fish infectious disease research has focused on the effects of pathogens on individual fish, even more specifically on the response of the body to that pathogen. Comparatively little work has been done on the role of disease in populations or biological communities. It is important to recognize that all populations have some amount of infection circulating and that a population can be healthy even if there are some sick individuals within the group. A healthy population can be defined as one that is meeting the goals and expectations we have for that population. For farmed fish, many of those expectations revolve around economically important parameters such as feed conversion, days to market, and growth rate. In ecology, variables such as fecundity, abundance, diversity and distribution are used to measure population health. Increasingly social variables, such as presence of animals for cultural reasons or social preferences for biodiversity are influencing views of population health.

Our understanding of the role of disease in free-ranging fish on these preferred ecological and social outcomes is rudimentary.

Salmon farming is a relatively young activity. With each passing year since its inception, more diseases have been discovered and/or studied, yielding new insights into how diseases affect salmon. However, there remain many unknowns and surprises that complicate prediction of ecological impacts. Care must be taken when extrapolating the results of one study or an experiment to a broader system. In some cases, different causes can result in the same effect. For example, a liver disease of Chinook salmon (hepatic megalocytosis) may result from either exposure to manmade pollutions or naturally occurring algal toxins (Stephen and Kent, 1993). In other cases, the same causal factor can result in different effects depending on species, strain, location and environmental variables (see below for more details).

1.3 Health, Disease and Sustainability

Having a clear definition of the preferred state of an environmental target is critical if one is to identify when harm has occurred (Calow and Forbes, 1997). When it comes to defining the preferred health status of fish, consensus is lacking. The majority of fish health research and policy deals with infectious diseases, most often at the level of the individual fish. A previous review of 10 issues of two prominent fish health journals found that in 194 articles, 28% dealt with the pathological response of a fish to an infection, 27% dealt with aspects of microbiology, 12% were concerned with treatment of individual fish, and 9% were concerned with the transmission and epidemiology of infectious diseases (Stephen and Thorburn, 2004). None dealt with the effects of disease on populations or ecosystems. This stands in contrast to standards approaches to ecological risk assessment where population survival and interactions, ecosystems, and biodiversity are the subjects of concern rather than individuals (Firestone, 2006; Gochfeld and Burger, 1993). An exception is for endangered species where individuals are critical to species survival and genetic diversity.

The pre-occupation with disease in fish health policy and research could lead us to conclude that the definition of fish health revolves around the presence or absence of diseases as opposed to a more comprehensive definition that considers elements such as age structure, productivity, sustainability and social value. Although virtually all fish health policies deal with infectious and parasitic diseases, stakeholders varying in how they ultimately wish to measure fish health. In some cases, people have concluded an unhealthy state to exist in the presence of infection without a measured impact on individual or population form or function. In other cases, people look only at the capacity to continue economic exploitation of a farmed or wild population as the true measure of health. Increasingly, the public, industry and regulators are turning to the concept of sustainability as a means to define, manage and measure salmonid health in a more comprehensively fashion. Stephen et al's 2007 review of sustainable salmon farming in British Columbia, Canada found that all major proponents and opponents of salmon farming held sustainability as a goal. There was, however, tremendous diversity in the indicators used to measure sustainable actions, lack of consensus on the criteria for sustainable salmon farming, and conflicting evaluations of the meaning of specific measures of sustainability.

The definition for sustainability is stakeholder dependent and therefore subjective, normative and changing over time (Glaser and Diele 2004). Because of this, there can be considerable difference of opinion on the criteria or desired states one wishes to achieve to ensure sustainability. Most conceptions of sustainable food production recognize there are 3 pillars to sustainability: (1) Ecological pillar – dealing with the quality, quantity and conservation of natural resources; (2) Economic pillar - concerned with the distribution of prosperity and (3) Social pillar – maintaining those social determinants of individual and community wellbeing such as healthy environments, community resources and cultural concerns.

The majority of sustainability concerns linked to salmon farms and disease are most directly tied to the ecological pillar of sustainability; often expressed in the concern that pathogens transferred from farmed to wild species will affect the abundance of a wild species, especially wild salmonids. The potential for such ecological effects to reduce or eliminate commercial, recreational or culturally significant fisheries have implications for the social and economic pillars of sustainability. There is unresolved debate regarding the effects of diseases arising in farmed salmon on ecological, economic and social sustainability. For example, on the issues of transfer of sea lice between farmed and wild salmon, Beamish *et al* (2006) argued that salmon farms and wild salmon can coexist without significant impact on the wild salmon. In contrast, Krkošek *et al* (2006) concluded that "as aquaculture continues its rapid growth, this disease mechanism may challenge the sustainability of coastal ecosystems and economies." The issue of sea lice is dealt more comprehensively in the companion report prepared by Review et al. When we entered the search terms "fish, disease, sustainability" into the PubMed search engine in 2007, four references appeared with only one relevant to sustainability as a management paradigm (Kroksek, 2006). Many of the papers fitting these search criteria in Google Scholar, spoke of a concern about the effects of disease on sustainability of wild fishes, but none provided data to draw reliable cause-effect conclusions about thresholds for disease prevalence or a specific disease management practice that were predictive of when sustainability would be threatened.

The question of whether or not diseases effects sustainability has not been systematically studied. Specifying a working model of sustainable food production in general has been extremely problematic partly because of the number and variety of parties involved in the debate (Rigby and Caceres 2001). Given scientific uncertainties and differences of opinion on the effects of salmon farming on the ecological pillar of sustainability and the little systematic study of the sociological implications of salmon diseases and we are left to political, legal or advocacy activities to shape the debate on the effects of disease on sustainability.

Our hope is that the reminder of this report will provide the reader and decision makers with sufficient background and guidance to formulate some consensus on this topic. However, we urge readers to be careful in drawing generic conclusions that are applied globally, nationally or even regionally. Whether or not a disease situation will affect sustainability can be very much affected by context. Impacts are felt locally first. Understanding the local ecology and local community perspectives is essential when examining sustainable situations. Failing to consider local variations may lead to generic, immeasurable and perhaps misleading evaluations of sustainability. Nevertheless, a broad understanding of disease and disease processes, as presented here will, we hope, provide local communities with a common understanding to formulate their strategic approach to sustainability as it relates to salmon farming.

1.3.1a. Factors Affecting the Effects of Disease on Sustainability

There are 3 variables that play a major role in determining the impact of a disease on a population. First, there is the range of the disease. A disease that extends over a wide geographic range, over long periods of time and affects a wide range of species has the potential to cause more harm than a disease limited to a single species in an isolated space for a brief period of time. Second, there is the abundance of the disease. A disease that affects a large proportion of the population or a pathogen that is present in abundance in a population or environment has a greater chance of being transmitted to and affecting fish or other animals than does a rare pathogen. The final determinant of impact is the effect of the disease on individual fish, fish population dynamics, ecosystem functions, economic benefits or other elements of sustainable systems.

1.3.1b. Range as a Determinant of Impact

Whether or not a disease is capable of causing important ecological, social or economic impacts depends in part on the ability of the pathogen causing the disease to spread in susceptible populations. Spread can be over time, over space or within and between individuals or species. Not all pathogens spread in the same manner or use only one mode of spreading. The routes of transmission have important implications on the likelihood of a disease spreading. For example, diseases that require 2 fish to actually touch each other to be transmitted, are more likely to be spread in situations where there are high densities of fish (and thus many opportunities for fish-to-fish contact) than in areas where fish are sparsely distributed. Figure 1 summarizes the major route of disease transmission. Tables 2 and 3 summarize the results of a review of the literature on proposed mechanisms of spread for a variety of fish diseases. These tables reveals two key points. First, there is variation in how pathogens are transmitted and thus we cannot consider the risk from each pathogen to be the same.

Transmission cycles of fish pathogens can be complex and variable. A tapeworm (*Eubothrium salvelini*) of sockeye salmon, for example, has 15 known fish hosts. This contrasts with another sockeye parasite (*Philonema oncorhynchi*) which has only five known fish hosts, four of which are Pacific salmon (McDonald & Margolis 1995). As fish health research has historically focused on commercially and recreationally important species, we know very little about the true host range of many fish pathogens. Increasingly we are finding fish pathogens affecting a wide array of hosts with different effects (e.g. Kent et al. 1998). For example, recent research on sea lice in British Columbia has resulted in new host records by demonstrating the presence of this parasite on stickleback; a species that had not been considered as a host in past surveys (Jones et al, 2006). Moran and Kent (1999) similarly found 5 non-salmonid hosts for an important parasite of farmed Atlantic salmon in Canada (*Kudoa thyrsites*). While these hosts were captured near a salmon netpen, the authors could not draw conclusions on if or how much overlap there was between the cycle of *Kudoa* in salmon and the non-salmonids. Despite such uncertainties, Murray and Peeler (2005) concluded that the pathogen exchanges between wild and farmed fish populations are inevitable. The preceding examples remind us that new discoveries on the routes of transmission of fish diseases can be anticipated with ongoing research.

A second important feature of table 3 is the fact that many fish pathogens can be transmitted in water. This finding supports concern about the movement of disease causing agents across salmon pen nets. However, simply because a pathogen can be waterborne, does not mean it is capable of moving from fish inside a netpen to fish outside. “Huge gaps exist in our knowledge regarding pathogen distribution in the environment, the environmental fate of pathogens and host susceptibility in aquatic environments” (LaPatra 2003). Many environmental variables influence the capacity of a pathogen to survive upon release from an infected fish and remain infectious in the environment when encountered by a susceptible fish. Some agents, such as sealice have evolved to move between fish through the water. Others have very short life spans in the water and require intimate co-mingle of fish to result in transmission. Table 2 provides some examples of pathogens with the potential for long environmental survival under appropriate conditions.

Most studies of environmental survival of pathogens have been under freshwater rather than marine conditions, so care must be extrapolating pathogen survival data from one ecosystem to the next. The lack of validated method for testing effluent from aquatic sources further complicates interpretation of studies of the spread and distribution of pathogens of salmon farm origin. The length of time a pathogen remains viable in the environment varies with temperature, salinity and pH of the water, among other factors. For example, *Aeromonas salmonicida* lives for 16-24 days in brackish water, 7-17 days in freshwater and 4-8 days in salt water (Stephen and Iwama, 1997). Local oceanographic conditions will affect the likelihood and frequency with which a pathogen can be transported from beyond the confines of a netpen and encounter free-ranging fish. Unfortunately, there has been very little work published that defines transmission lengths and distances for most salmon diseases under typical farming conditions. The movement of sea lice between wild and farmed fish is perhaps the best studies example (see sea lice report for details). Some case studies of other diseases suggest certain

Table 1- Disease distribution in selected production areas of the world

Disease in salmonids	Pathogen type	Listed with OIE[#]	Main source of information	Detected*				
				Canada East coast	Canada West coast	Norway	Scotland	Chile
ISA	virus	Y	1	WF	N	WF	WF	F (W?)
IHN	virus	Y	1	N	WF	N[3]	N[2]	N
VHS	virus	Y	1	W	WF	W	W	N
IPN	virus	N	6	N	W	WF	WF	WF[5]
PD	virus	N	4	N	N	F	F	N
BKD (*Renibacterium salmoninarum)*	bacteria	N		WF	WF	W[3]	WF[2]	WF[1]
Furunculosis (*Aeromonas salmonicida*)	bacteria	N		WF	WF[13]	WF[3,4]	WF[2,11]	WF[12] (atypical *A.s.* only)
SRS (Piscirickettsia salmonis)	rickettsia	N	7	F?[9]	WF	F[4]	F[8]	FW[5]
Gyrodactylus salaris	monogenean ectoparasite	Y	1	N	N	W[3]	N[2]	N
Kudoa thyrsites	myxosporean parasite	N	10	N	WF	W (North Atlantic fishing grounds)	W	W

F= farmed fish, W=wild fish, WF= Wild and Farmed Fish, N= not present, * http://www.oie.int/eng/maladies/en_classification2009.htm?e1d7

SOURCES

1. http://www.oie.int/eng/normes/fmanual/A_summry.htm
2. http://www.frs-scotland.gov.uk/Delivery/standalone.aspx?contentid=677
3. http://www.vetinst.no/eng/Research/Publications/NOK-Reports
4. http://www.vetinst.no/eng/Research/Publications/Fish-Health-Report
5. http://www.eurofish.dk/indexSub.php?id=3548
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8. Reid HI, Griffen AA, Birkbeck TH. Isolates of Piscirickettsia salmonis from Scotland and Ireland Show Evidence of Clonal Diversity. Appl Environ Microbiol 2004 Jul 1;70(7):4393-7.
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11. Grant AN, Laidler LA. Assessment of the Antimicrobial Sensitivity of Aeromonas-Salmonicida Isolates from Farmed Atlantic Salmon in Scotland. Vet Rec 1993;133(16):389-91.
12. Bravo S, Midtlyng PJ. The use of fish vaccines in the Chilean salmon industry 1999-2003. Aquaculture 2007;270(1-4):36-42.
13. http://www.agf.gov.bc.ca/ahc/fish_health/bcsfa_reports.htm

diseases of salmon farms can move considerable distance. For example, furunculosis was described as spreading 10km between farms in British Columbia (Needham 1995).

Table 2. Environmental survival features of selected pathogens (adapted from Stephen C, Dawson-Coates J, DiCicco E. 2007. Pathogen Risks Associated with the Diversion of Water from Devil's Lake into the Red River Drainage. Report to the International Joint Commission)

Pathogen	Environmental survival features
Infectious pancreatic necrosis virus	Considered very stable in water. Virus and virus-contaminated material described to have flowed 19.3 km downstream from the effluent of IPNV-contaminated fish hatchery.
Epizootic hematopoietic necrosis virus	Extremely resistant to drying. Can survive for months in water. Presumed to persist for months to years on a fish farm in water and sediment and on plants and equipment. May be transferred on nets, boats and other equipment, or in fish used for bait by recreational fishers.
Renibacterium salmoninarum	Can survive in filtered freshwater for 28 days. Reported survival in fish tank sediment/faecal material (but not in overlying water) for up to 21 days in absence of any fish is documented. Appears to be unable to compete with the member of the normal aquatic micro flora.
Yersinia ruckerii	Capable of surviving in the fresh water column up to 16 weeks after an outbreak. May be capable of surviving in the environment in a non-culturable state that is not readily cultured on conventional media. Some aquatic invertebrates and mammals may harbour large number of the pathogen.
Aeromonas hydrophila	Exists in most natural freshwater ponds, streams, reservoir, and bottom mud where it survives as a facultative organism
Heterosporidia	Has lived and retained its viability in water at 4ºC for about one year.

Figure 1. Modes of disease transmission

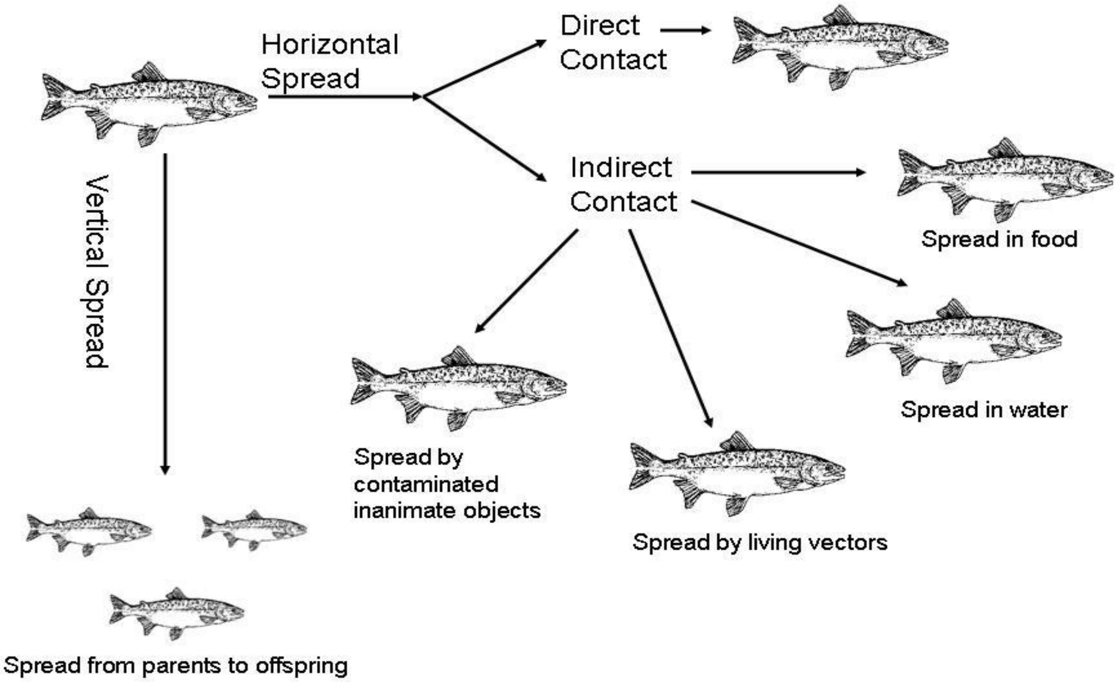

Table 3: Transmission routes described in the literature for common fish pathogens (adapted from Stephen C, Dawson-Coates J, DiCicco E. 2007. Pathogen Risks Associated with the Diversion of Water from Devil's Lake into the Red River Drainage. Report to the International Joint Commission)

	TRANSMISSION ROUTES							
Pathogen or Disease	Waterborne transmission	Direct contact transmission	Oral transmission	Vector transmission (invertebrates)	Vector transmission (vertebrate.)	Vertical transmission	Indirect transmission (fomites)	Intermediate host
ISA	**X**	**X**			**hypothesis***		**X**	
VHS	**X**	**X**			**X**	**hypothesis***	**X**	
IHN	**X**	**X**		**X**		**X**		
IPN	**X**	**X**		**X**		**X**	**X**	
OmVD	**X**	**X**		**X**		**X**	**X**	
EHN	**X**				**X**		**X**	
Salmonid Herpesvirus	**X**	**X**				**hypothesis***		
BKD	**X**	**X**	**X**			**X**		
Plesiomonas shigelloides	**X**							
Shewanella putrefaciens	**X**							
MAS	**X**	**X**		**X**	**X**	**X**	**X**	
Furunculosis	**X**	**X**						
Columnaris	**X**	**X**						
Mycobacteriosis and Nocardiosis	**X**	**X**	**X**			**X**	**X**	
Piscirickettsiosis	**X**	**X**		**hypothesis***		**hypothesis***		
Salmonid Ceratomyxosis	**X**							**X**
PKD	**X**							**X**
PGD	**X**	**X**						**X**
Heterosporosis	**X**	**X**	**X**		**hypothesis***	**hypothesis***		
Gyrodactylosis	**X**	**X**						

hypothesis = has been a suggested but not proven route. For vertical transmission, the hypothesis is due to the finding of the agent on, or in, gametes, reproductive organs, or reproductive fluids

Aquaculture activities in themselves can contribute to the spread of pathogens. There are many cases where the movement of fish for public or commercial salmon farming or even the movement of fish products has been clearly linked to the movement of pathogens into new locations, even crossing ecological boundaries. Whirling disease in the Unites States (Hedrick et al. 1998), Gyrodactylus in Europe (Bakke and Harris 1998), and IHN in BC (St-Hilaire 2002) are all examples of diseases that have been moved by the movement of fish, water or equipment tied to public or private aquaculture. While waterborne infections may be the focus of most interest, past experience and the available literature indicate the movement of diseases along with the movement of fish has played the most important role in the spread of diseases in space and between species. Gozlan et al (2006) reviewed the possible effects of pathogens on European fish and concluded that introductions of pathogens and parasites that affected the diversity of wild fish populations were invariably associated with live fish movements.

In general, the likelihood of transmission decreases dramatically as the distance between a susceptible host and a viable pathogen increases. How far apart wild and farmed fish must be held will vary between diseases due to variation in factors such as route of transmission, environmental survival of the pathogen, and mechanisms for moving the pathogen and thus will vary from diseases-to-diseases and from farm-to-farm. These are discussed in more detail in chapter four.

1.3.2. Abundance as a determinant of impact

It is a general epidemiological tenant that both the number of diseases and the disease incidence should increase proportional to host abundance (barring efforts to control those diseases) (Tilman et al, 2002). Murray and Peeler (2005) stated that aquaculture practices frequently result in high population densities and other stresses that can increase the risk of infection establishment and spread. Epidemiological principles tell us that the amount of disease in a population increases if either (or both) the probability of exposure to a pathogen increases or the amount of susceptible individuals in the population increases. By holding a large concentration of susceptible animals in an area, the potential for introduced pathogens to reach high levels in the environment or in susceptible populations should be higher if a disease cannot be quickly and effectively managed. Such principles have lead people to conclude that we should anticipate that as aquaculture grows, disease issues will also grow. The conclusion that salmon farms serve as local multipliers of pathogens in the marine environment because of the large concentration of susceptible fish has been the foundation of many concerns about fish farming and disease. Most attention has been focused on sea lice where some models suggest salmon farms provide substantial amounts of lice larval, to the point of altering sea lice epidemiology (Gozlan et al, 2006).

Basic epidemiological tenants serve as a useful strategic guide when planning disease prevention, but can often fail us when we seek prediction of local effects of pathogen levels in populations. The complexity of this situation reflects that fact that there is not a one-to-one, straight line relationship between the amount of pathogens in a population and the amount of disease that will result. Many ecological factors complicate the association between abundance of pathogen in an environment and prediction of specific disease outcomes.

When thinking about abundance, we need to think in relative and not absolute terms. Regardless of the abundance of a pathogen in an environment, if a susceptible fish is not effectively exposed, pathogen abundance is irrelevant as transmission will not occur. For example, *Yersinia ruckerii* (the bacteria causing enteric redmouth disease), can be readily transmitted in water but a previous survey of wild fish around fish farms experiencing this disease did not find evidence of diseases in wild fish (Roberts 1985 in Stephen and Iwama, 1997). It has been proposed that salmon farms might increase this relative abundance by (1) multiplying and maintaining the amount of pathogens in a local environment, (2) moving a pathogen out of a cages by escaped fish or (3) attracting wild fish to cages where sick fish are present.

It has been postulated that escaped fish carry with them infections they can transfer to wild fish. For example, escaped fish are believed to be the source of furunculosis in 20 Norwegian rivers (Hastein and Linstad, 1991.) Such transfer requires the escaped fish to be shedding the pathogen, to be healthy enough to live long enough to come in contact with a wild fish and that wild fish to be unable to cope with the exposure to the infection. It, therefore, seems unlikely that a sick fish will be an effective source of pathogens for wild fish given that sick fish typically do not keep up with their healthy cohorts (Stephen and Ribble, 1995). A variety of salmon diseases can result in a carrier state in asymptomatic fish (such as furunculosis, bacterial kidney disease, infectious hematopoeitic necrosis, infectious salmon anemia, infectious pancreatic necrosis). We found no studies that examined what proportion of escaped salmon that includes asymptomatic disease carriers and how many survive long enough to transmit their pathogen to another fish. Asymptomatic, persistently infected fish typically do not shed as much pathogen as a sick fish, but their shedding happens over an extended time period and shedding rates could increase with stress. Opportunities for transmission through co-mingling will be lower in jurisdictions where the species of salmon reared are different than the wild species and social and ecological barriers would reduce the interaction of escaped and wild fish. Escape rates in salmon farms have decreased dramatically in recent years in many jurisdictions. All of these factors reduce the risk of escaped fish transmitting diseases to wild stocks, but the level of risk still cannot be quantified due to gaps in knowledge.

It is widely known that wild fish do inhabit and/or transit within marine cages. The presence of waste feed or excrement, the use of lights at night to work and the shelter provided by a salmon farm are examples of ways in which a salmon farm might attract wild fish. While there is evidence that the some of the species frequenting cages can be infected with the same or similar pathogens as those found within the farmed salmon population, little is known about the extent of movement of infectious agents between these two groups. Perhaps more significantly, we could find no study that characterized the frequency and duration of time wild salmon came within a distance of a netcage that would allow effective exposure to directly transmitted pathogens or pathogens that can only be transmitted over a short distance in the marine environment.

1.3.3. The Magnitude of Effect as a Determinant of Impact

There is sufficient evidence that salmon pathogens and parasites can be found in wild and farmed salmon and that they can cause disease and death in infected fish (Stephen and Iwama, 1997). There is also reasonable evidence to conclude that pathogens and parasites can be shared or transmitted between wild and farmed salmon. However, the extent, frequency and implications of these exchanges remain largely unknown or unquantified. The data available to specify a prevalence, intensity or distribution of infection that will lead to unsustainable effects is sparse, contradictory and inconclusive. In some cases some authors have implicated farmed salmon as the source of this parasite which had significant negative impacts on wild salmonids (Krkošek, 2006). In other cases, fish pathogens of farmed origin have been found in wild fish with little effect. Noakes et al (2000), for example, claimed surveys of pathogens in wild and hatchery fish show no patterns that could be attributed to salmon farming in British Columbia. Reasons for these different effects in farmed versus wild fish can be many including differences in the virulence of the strain of pathogen, differences in population immune status or differences in environmental stressors. Most investigation and modeling of fish disease we found dealt with single diseases in relatively homogeneous populations, many involving laboratory-based research, rather than trying to study diseases in natural and complex systems. None observed medium-to-long term ecological effects of diseases that were believed to have been introduced into a wild fish population.

There are some significant challenges to understanding the ecologic effects of diseases in wild salmon. One of the major obstacles has been the fundamental problem of tracking healthy and diseased wild salmon in their natural habitats, especially in the marine phase of their lifecycle (Bakke and Harris, 1998). This has resulted in most of our knowledge on diseases in wild fish coming from sporadic surveys, focused on a limited part of a life cycle in opportunistically captured fish rather than a systematic and representative characterization of the relationship between diseases and population health. Good et al (2001) showed the danger of such an approach when they found that diseases in Ontario hatcheries clustered by species and age class within a location. Stephen and Ribble (1995) showed a similar risk of extrapolating the findings from subsets of farmed salmon populations to the entire group. A second challenge is the problem of separating out the compounding effects of other environmental stressors or the effects of human response to a disease on the impact of an introduced infectious agent. For example, recent findings show that a combination of poor water quality and infectious pancreatic necrosis virus was required to cause reductions in wild trout populations (Gozlan et al. 2006). Whirling diseases serves as another example. While this is one of the most studied and managed diseases of wild salmonids, there is debate about how much of the effect is due to the parasite alone, and how much is due to the compounding effects of degraded environmental quality. Despite Whirling Disease being one of the most extensively studied diseases of wild salmonids, there is still significant uncertainty about the true effects it has on populations. A third major challenge arises from limitations in our diagnostic options for studying fish diseases. The clinical performance characteristics of most fish diseases tests remain un-quantified for free-ranging fish. The likelihood of false positive and false negative results is therefore unknown in many cases. This can lead to significant uncertainty about how to interpret test results (Bruneau 2002), especially when they are used in species for which the test was not originally intended.

The fourth challenge is being able to see the "entire picture." Due to a combination of limited resources and lack of knowledge of many facets of the biology, ecology and epidemiology of fish diseases, it is not possible for studies to sample all relevant host species when looking for the presence or impacts of diseases in wild populations. Sometimes, this can lead to significant misunderstandings. For example, the finding of viral hemorrhagic septicemia virus in hatchery reared salmon in Washington State, USA, was initially interpreted as evidence of the introduction of an exotic pathogen (Myers and Winton 1996). Subsequent investigations of wild marine fish found this was instead an endemic infection of the region that was previously unrecognized (Amos et al, 1998). In another instance, biases in study methodologies resulted in an endemic disease causing low level mortality to be mistakenly classified as a spreading epidemic causing extreme death losses in farmed salmon (Stephen and Ribble, 1995b)

Table 4. Potential effects from disease that can be hypothesized to occur across different levels of biological organization.

Unit of Concern	Potential effects
Individual fish	Death, morbidity and sub clinical infection that reduces individual fitness
Fish Populations	Reduced abundance and distribution due to disease associated mortality or reduced fitness. Special concerns for species at risk
Fish Communities	Altered fish predator-prey relationships. Impacts on non-fish species, including intermediate hosts and species dependent upon fish
Fish Ecosystems	Impacts on biodiversity, functional integrity and nutrient and energy dynamics. Interactions of new pathogens)with existing ecosystem stressors may result in unanticipated effects
Human communities	Impacts on recreational, cultural and commercial fisheries. Effects on trade if disease status changes of a zone changes.

Despite these challenges, there are several case studies providing evidence that pathogens may affect fish population dynamics. The ectoparasite *Ichthyophthirius multifiliis* apparently affects mate choice by stickleback (Apanius & Scah 1994). Infections with *Kudoa paniformis* in Pacific hake have been associated with dose-related depressions in female fecundity (Alderstein and Dorn 1998). Outbreaks of *Ichthyophonus hoferi* in herring (*Clupeidea* sp.) were judged to have significant effects on stock size (Patterson 1996). Parasitism was found to be one of the main causes of death in fish in a Manitoba lake because parasitized fish were smaller than non-infected fish and thus more susceptible to predation (Szalai & Dick 1991). A similar relationship was noted in the Netherlands where cormorants caught a disproportionately higher number of fish infected with a tapeworm (*Ligula intestinalis*) than non-infected fish (van Dobben 1952). Mesa et al (1998) demonstrated that Chinook salmon challenged with *Renibacterium salmoninarum* were more susceptible to predation by northern squawfish and smallmouth bass under experimental conditions. It is not clear how these and other cases reflect long-term effects on ecological sustainability or if they are relevant to diseases of farmed salmon.

The way a pathogen manifests in an ecosystem will depend on variations in the proportion of an ecosystem that is subject to the pathogen, the intensity and distribution of the pathogen and susceptible hosts, and the pattern of other environmental and biotic determinants. Historic practices of rearing different hosts in new geographic areas (ex. Atlantic Salmon in the Pacific ocean), or indigenous species being reared in a different environmental condition (netpens) has resulted in diseases and patterns of diseases that would have been difficult to predict. (Kent 2000). Under such conditions, new or unusual infections or effects can be generally anticipated, but not specifically predicted. In some cases pathogen evolution within a farmed setting may lead to a pathogen that causes less death or diseases thus potentially reducing its impacts; such as in the case of furunculosis (Austin and Austin, 1993).

Susceptibility to infection can vary and is affected by innate, acquired and external factors. Some species may be inherently resistant to certain pathogens. Different life stages may have (or not) acquired immunity (such as may be transferred in eggs). Sometimes, susceptibility can be enhanced due to immunosuppressive stressors. There is a lack of information on variations of susceptibility within species between locations, on the full range of pathogen susceptibility within a diversity of species in a fish ecosystem and on the dynamic nature of changes in susceptibility over the life course of a fish. The wide variety of immune responses and population responses that occur in the face of disease make it very unlikely that coexisting diseases will act independently (Adler & Brunet 1991). For example, the virus responsible for erythrocytic inclusion body syndrome is thought to increase the susceptibility or effects of other disease agents in salmonids (Rodger et al 1991). The pre-existing richness and saturation of fish hosts with parasites can affect the establishment of introduced parasites (McIntyre, 1996). The disease history of a population will, therefore, likely affect the effects of a newly introduced disease. Susceptibility to infection can be different between species as was demonstrated in Chilean research which showed how susceptibility to the parasite *Caligus rogercressi* varies between farmed rainbow trout, Atlantic salmon and coho salmon (Gonzalez et al, 2000). Genetic differences within a species can also affect the severity of infections, as was seen in Norwegian strains of wild and farmed Atlantic salmon and their response to challenge infections with sea lice (Glover et al 2004). Non-disease related variables such as age, spawning behavior, feeding patterns and life-history can affect opportunities for pathogens to be transmitted and maintained within sub-groups of the same species and therefore further complicate prediction of the effects of introduced pathogens. Ecological differences within the same species can result in different infection status. For example, Bailey & Margolis (1987) showed that, within the same lake, there could be ecologically isolated groups of juvenile sockeye salmon (*Oncorhynchus nerka*) that use different parts of their environment and thus have different parasites. In the ocean, there will be many different fish populations that interact to varying degrees. One group of fish can be virtually separate from other members of a biological community because of its habitat requirements and behaviors. All of these biotic factors will play major roles in creating heterogeneity leading to high local variability of transmission and infection patterns (Kitron, 2000), thus complicating prediction of how well we can extrapolate case studies and observations from one region or site to others. There was a virtual absence of comparisons of local variation in epidemiological interactions of wild and farmed fish .

While there is compelling evidence that fish disease can have population impacts under some conditions, there is also evidence that challenges the proposition that the disease invariably results in undesired population effects. Yasutake et al (1986) detected six different parasite species in Columbia River Coho (*Oncorhynchus kisutch*), but did not find any relationship between parasite burden and survival. A large number of parasites, bacteria and some viruses were detected in wild fish in northern British Columbia, but only *Ceratomyxa shasta* was associated with disease (Stephen and Iwama, 1997). Similarly, there are jurisdictions that have *Myxobolus cerebralis* present (the agent of Whirling Disease) without apparent effects on wild stocks (Modin 1998). Whether these findings reflect biological reality or are artifacts of limitations in sampling and study methods is unknown.

The World Organization for Animal Health (OIE) recognized that the poorly understood life-cycles and survival of fish pathogens makes risk assessment difficult, even to the most studied models (http://www.oie.int/eng/publicat/ouvrages/a_101.htm). As we move from the individual to ecosystem levels, we are faced with expanding levels of uncertainty regarding causal relationships of pathogen introduction and adverse effects. Not all of these uncertainties are linked to the pathogen. Epidemic theory tells us that five variables determine whether or not an infectious or parasitic agent will persist in a population: (1) the density of the hosts; (2) the probability of transmission per contact between susceptible and infectious hosts; (3) the disease-induced mortality rate; (4) the per capita death rate of uninfected hosts and (5) the rate of recovery from infections (Anderson 1991). Such theory reminds us that population features independent of pathogens (such as background death and birth rates) are critical determinants of the fate of a pathogen in a population as well as the likelihood of a disease being established, spread and maintained in populations. Though not a primary focus of this project, we found few reports of values for these population parameters for species potentially interacting with salmon farms. Data that are available are limited due to the infrequency of population surveys. Unless we assume that all populations have similar population dynamics, we cannot assume that an introduced agent will have homogenous effects in all bodies of water and populations

1.3.4. Other factors affecting impacts

Legislative considerations will affect the impacts of a pathogen. Significant legislation, conventions, policies and standards recognize that it is undesirable economically and ecologically to import or introduce foreign pathogens. There is a wide range of international and national laws, regulations and agreements associated with the prevention and control of the introduction of alien and invasive species (Table 5). While many deal with the movement of plants and animals, others, such as the North America Fisheries Policy are concerned with the movement of exotic pathogens. Both the US Fish and Wildlife Service and the Canadian Department of Fisheries and Oceans have as part of their policy goals the prevention of the spread of pathogens into areas where they are not known to occur[2].

Despite these acts, laws and conventions, we found no clear legal criteria or policy statement to specify a threshold wherein a pathogen introduction is ecologically harmful. Legal definitions of harm, risk and health tended to be nonspecific and non-prescriptive. A specific legally defined threshold will remain elusive due to a lack of research and methods that look at pathogens in a natural setting where there is variable host susceptibility, interacting pathogens and non-pathogens stressors affecting population stability.

Table 5. A partial list of treaties, acts or other legislation concerned with translocation of biota, including pathogens, in water in North America

International Treaties:
- *Boundary Waters Treaty*
- *North American Free Trade Act*

United States:
- *U.S. National Environmental Policy Act*
- *U.S. Clean Water Act*
- *Dakota Water Resources Act*
- *Garrison Diversion Reformulation Act of 1986*
- *National Invasive Species Act*
- *Presidential Executive Order on Invasive Species, 1999*
- *Treaty on Boundary Waters*
- *Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990*

Canada:
- *International Boundary Waters Treaty Act of 1986*
- *Environmental Assessment Act of 1992*
- *Environmental Protection Act*
- *Manitoba Water Protection Act*
- *Canada Water Act*
- *Fisheries Act*

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[2] http://www.fws.gov/policy/713fw1.html

http://www.dfo-mpo.gc.ca/Aquaculture/health-sante_e.htm

One standard used to identify a priority pathogen is whether or not the pathogen is endemic or exotic to the receiving environment. The North Atlantic Salmon Conservation Organizations (NASCO, 1993) concluded that damage to wild populations arising from the introduction of exotic diseases could be so severe as to render certain wild salmon stocks extinct. Article 8 (h) of the Convention on Biological Diversity, requires that each Contracting Party shall, "as far as possible and as appropriate, prevent the introduction of alien species which threaten ecosystems, habitats or species". Two objectives of the World Conservation Union (IUCN) guidelines for the prevention of biodiversity loss caused by alien species include; (i) encouraging prevention of alien invasive species introductions as a priority issue requiring national and international action and (2) to minimize the number of unintentional introductions and prevent unauthorized introductions of alien species. Many of the rules around the movement of animals for trade as established by the OIE are built on steps to prevent the introduction of non-indigenous pathogens into a receiving country. It is, however, challenging to differentiate a disease newly discovered in a fish farming region from an introduced disease. For example, in the early days of salmon farming in British Columbia, many apparently new diseases were "discovered" in salmon farms. None were indeed new rather they had gone undetected due to lack of study of wild adult salmon (Stephen and Iwama, 1997).

Most fish pathogens risk assessments do not consider the effects of fish pathogens on non-fish species. Recent evidence suggests that introduced fish can be carriers of pathogens that are important for other species. Kiesecker et al (2001) provided evidence that introduced fish may serve as a vector for a pathogenic oomycete, *Saprolegnia ferax*, which has been associated with embryonic mortality of amphibians. Jancovitch (2005) has produced evidence to support the hypothesis that iridovirus of salamanders, a recently emerged North American disease, originated from sport fish such as rainbow trout. This aspect of the salmon farming debate has received very little attention and thus cannot be commented on further.

Social values and cultural perspectives play an important role in the salmon farm disease debate. Because questions of harm have not been resolved by science and because the marine phase of salmon farming can affect common resources, competing preferences for environmental management outcomes result in conflicting views of the impact of salmon farm associated diseases. Coastal BC indigenous cultures, for example, have been and are heavily reliant on wild salmon culturally and economically. Most BC coastal communities until very recently relied on the commercial salmon fishery as a cornerstone of their social and economic sustainability. For many industry critics, salmon farms do not hold inherent value as part of a cultural fabric and are seen as competitors rather than contributors to economic, social and environmental sustainability. There are cases where critics support the extrinsic value of salmon farming and seek to benefit from its economic activity without engendering environmental risks by advocating for land-based farms. Industry supporters, however, claim this is a non-sustainable situation from the farmers' perspective due to technological and economic barriers to closed-containment production. (http://www.leg.bc.ca/CMT/38thparl/session-3/aquaculture/reports/Rpt-AQUACULTURE-38-3-2007-MAY-16.htm#witnessBriefings). While the goal of sustainable agriculture often includes sustaining farms, the debate around sustainability and salmon farms has focused less on sustaining farms and more on ensuring that farms do not impede the sustainability of natural resources of ecological, economic or social significance. Any possibility for salmon farm diseases to affect other coastal resources can be harshly judged.

Changes in environmental quality and climate must also be considered when assessing potential impacts. Most risk assessments have considered the effects of an introduced pathogen under current environmental conditions. It is well established that environmental variables, including water quality, community diversity, the presence of pollutants, habitat quality and other variables can affect the manifestation and effects of fish disease. Therefore, it is reasonable to assume that the effects of a pathogen can change as the susceptibility of population changes due to changing environmental stressors. The looming issue of climate change and its effects on fish pathogens has not been well studied but cannot be ignored as a possible driver of changing patterns of risk over time (Marcogliese, 2001). It is reasonable to assume a pathogen could be transferred today, but not cause adverse effects for years to come due to changing environmental or population features.

Overview of disease control

Table 6 summarizes the 8 general ways diseases can be controlled. These are discussed in more details in chapters two-to-five. Without a doubt, biosecurity obtained through isolation and environmental management is a predominant and important part of not only protecting farmed fish but as a way to limit exposure risks for wild fish.

Table 6- Basic Categories of Methods for Disease Control

Category	Explanation and comments
Mass slaughter	All individuals in a population at risk that were potentially exposed to the disease are killed and disposed of
Test and slaughter	Only fish that test positive for the presence of the disease or pathogen are killed and destroyed. As most tests for fish disease require the fish to be killed to achieve a diagnosis, this is typically not an alternative under commercial farming conditions
Quarantine or isolation	Exposed and/or infected individuals are separated from other susceptible individuals in a manner that prevents transmission of a pathogen. Open netpen systems or closed pens that do not have capacity to treat water are not conducive to this intervention
Mass treatment	All infected or exposed individuals are treated with a drug or chemical to kill the pathogen and reduce it to a level w2here it cannot no be sustained and cause harm in individuals and populations.
Mass vaccination	Vaccines are used to bolster the immune system, allowing it to combat the infection. This action is best used in groups not yet exposed to a pathogen due to the time delay between vaccination and a protective immune response
Environmental management	Changing features that stress fish and increase their susceptibility (water oxygen, water temperature, crowding, nutrition etc) or facilitate exposure to the pathogen (poor hygiene and biosecurity etc) in a manner to reduce exposure or susceptibility to infection
Education	Providing information to allow for appropriate assessment of the significance of a disease (and thus need to act), the best way to treat and/or best way to prevent a disease
Surveillance	Monitoring a population until such time as a specific threshold of diseases signals the need to intervene
No action taken	

Many fish farm management practices aim to ensure that, if a disease or infection is present, its spread is limited to a small number of fish over a short period of time so as to reduce the costs from drug use, fish deaths or effects on marketability. Limiting or preventing within-in farm and between-farm spread of disease is therefore a major focus of health management plans. Reducing or eliminating pathogens loads in and around farms, building some form of barrier to prevent “spill-over” between wild and farmed fishes and/or waste management pre-occupies strategies to prevent spread from farms into wild fishes.

Hygiene and waste management practices are a cornerstone of disease prevention on farms. Preventing on-farm harvest and processing has been seen to reduce wastes and blood in the water which can facilitate pathogen spread or survival (Murray and Peeler, 2005). Prompt removal of dead fish from pens is protective against certain diseases such as ISA (Jarp and Karlse, 1997). Barriers can be built to separate wild and farmed fish. This is best accomplished in the freshwater hatchery phase where ground water is used, wastes are properly managed and farmed fish are held in land-based tanks. One of the major criticisms of open sea-pen salmon farming is the netting or the pen structure inadequately separates wild and farmed fish. Not only can some pathogens move in an out of the pen through water movement, but also small wild fish can enter and exit the pen with ease, fish wastes are not retained in the pens and farmed salmon periodically escapes their enclosures. The fact that pathogens and parasites can move between the farmed and wild components of a marine cage system is proven by the fact that farmed salmon get sea lice. Sea lice are marine organisms and as such, young salmon being brought to sea from fresh water hatcheries should be free of lice infestation. Therefore, they must acquire sea lice that are found in the marine waters.

Barriers to transmission can be achieved, though imperfectly, by siting farms in a manner that increases the distance between farms and ensures farms are remote from critical wild fish habitat, such as spawning streams. This is an imperfect system because some pathogens especially parasites with planktonic stages, can move considerable distances on tidal currents, some diseases can be moved by other wildlife (e.g. IPN and birds) and because people and equipment do move between farms and can transport pathogens. Success can be enhanced when neighbouring farms agree to standard protocols for fish and equipment movement as well as to a certain standard of hygienic practice. In some jurisdictions, such as British Columbia, such a standardized approach is a required part of farm licensing.

Removing infected fish from the population serves to reduce the amount of time a fish can be shedding infectious material into the environment and thus decreases the likelihood that another fish becomes infected. There are three main ways to achieve this end. Mass killing of fish all fish (infected or not) in an affected or exposed population has been practise for diseases of significant concern; such concern has historically been defined as diseases that, if present, would affect opportunities for trade. Unlike for some diseases of mammals and birds, selective slaughter (control of disease spread by killing only fish that test positive for the disease) is rarely done for fish because there are few tests that can be used on live fish to diagnose most diseases and because of logistical issues with handling and separating infected and uninfected fish.

However, this has been applied at the cage-level when the group tests positive to ISAV. The final way to rid a population of infectious individuals is mass treatment with drugs or chemicals. The selection of which of these 3 methods to use will depend on legislation, the severity of the disease and the availability of effective medications.

Are marine fish farms different than terrestrial animal farming?

Some supporters of salmon farming argue that this system for food production is no different than other forms of animal food production and should therefore be treated with equivalent policies and public scrutiny. Critics of salmon farming have argued that if salmon farming is merely one more form of food animal production, we should learn from this history and govern the industry accordingly to prevent movements of disease. There is a long history of the transmission of diseases agents from livestock to people and to wildlife. These transmissions have shaped societies and altered ecosystems. In addition, the effects of agriculture on water quality, air quality and habitat have been well documented. If one were to compare terrestrial animal and salmon farming only on a basis of the volume of published science showing that diseases move from farm systems to wildlife or people with detrimental effects, terrestrial farming would compare very unfavorably. Around the world, people spend billions of dollars managing the wildlife-agriculture interface. Currently in North America, the exchange of diseases such as brucellosis and tuberculosis between bison and elk and cattle affects conservation programs and agricultural trade. Conflicts between domestic sheep farmers and organizations dedicated to conserving bighorn sheep revolve around the issue of disease transmission. In the United Kingdom, the impact of badgers as a potential source of tuberculosis for cattle cost millions of pounds annually. Although we know substantially more about how diseases work in birds and mammals than fish, wildlife managers are still faced with many of the same uncertainties as fisheries managers and thus are often left without a definitive scientific basis to predict the implications of disease exchange. Looking for a science-based solution alone has typically been an unsatisfactory path to resolving wildlife-agriculture conflicts.

One difference between terrestrial farming and salmon farming is the real or perceived capacity to contain risks. Land-based farming is typically conducted on privately owned or leased land with visible borders (fences and barns) whereas marine salmon farming occurs in the sea where its wastes and pathogens might freely defuse beyond the border of the cage. While there is a clear legal distinction between farming on common resources such as the sea versus farming on private resources, the distinction is not equally clear from a biosecurity perspective. Without a doubt, it is easier to contain pathogens and enforce biosecurity protocols within a farm that has “seal-able” boundaries. But, the literature and newspapers are full of example where pathogens enter or exit land-based farms. Air, like water, can serve as media for disease spread as can the movement of animals, equipment and personnel. Avian influenza, Nipah virus, foot and mouth diseases, chronic wasting diseases are but a few recent examples of significant diseases that have moved between wildlife and farmed animals. Although agriculture comes under intense public and regulatory scrutiny if it impacts public resources, such as water or air quality or food safety, the historical approach to managing the wildlife-agriculture interface has been to be protective of agriculture and agriculture trade. As a more recently evolved industry, the burden of public concern for salmon farming has been in the opposite direction practically from its inception. This public concern is not necessarily reflected in regulatory standards around the world.

Unlike in terrestrial farming, in many major salmon farming areas (North America, United Kingdom, Norway), salmon farmers are rearing the same species as can be found naturally in the same environment. The genetic and ecological implications of this practice should be discussed, but are not the subject of this report. From a disease perspective, the implications of this shared use of the same species largely revolve around issues of disease susceptibility. The land-based analogy to this is game farming. In some jurisdictions, regulators prevent game farming of species that roam free naturally in the farming region, but this is in no way a universal management approach. In a North America context, tuberculosis and chronic wasting disease perhaps stand as cautionary tales about the need to understand epidemiological opportunities for disease transmission when constructing farms.

The opportunities to control diseases in wildlife or free-ranging fish are extremely limited and are discussed in chapter four. Delivery of drugs or vaccines is not a feasible option. Tracking animals to find and capture enough to interrupt transmission via mass slaughter or isolation is often impractical unless fish are schooling, near-by and can be caught before transmission to other groups is likely to have occurred. Managing the natural environment is rarely a feasible option, especially for widely ranging species such as wild salmon. In terrestrial farming, the wildlife-agriculture interface is most often managed by (i) building barriers; (ii) site selection for farming activities or (iii) culling of wildlife that threatens farmed species. Barriers to exclude wildlife from farm lands or physical features of the farm include fences that prevent direct contact or strict confinement of animals within a barn. Although not always based on knowledge of the ecological and epidemiological interactions of wild and farmed species, and certainly not being 100% effective, this approach has frequently been met with success.

A final important difference between salmon farming and terrestrial farming involves the availability of tools to prevent and manage diseases of farmed animals. Although a large international industry, salmon farming does not receive equivalent attention from drug and vaccine producers or investment by research funding agencies as do its cousins in terrestrial farms. The result is a smaller armament of technological interventions available for prevention, containment and control of infectious diseases.

Chapter 2: Disease and Infection Avoidance

2.0 Introduction

Aquatic animals have been moved across national and international boundaries for many years. These have taken the form of aquaculture stocks, ornamental animals and plants as well natural, anthropogenic and accidental introductions of new species. Although some of these areas are highly regulated (e.g. aquaculture and the ornamental aquatic trade) the introduction of diseases through trade, animal migration or via accidental introduction via a third party are much more difficult to control.

Some of these accidental hitchhikers such as ISAV, KHV or *Anguillicola crassus* have had devastating impacts on farmed and wild fish stocks leading to serious economic impacts or adversely affecting the recovery of overfished wild fish and shellfish stocks. Although it may be near impossible to control the natural transfer pathogens in migrating animals such as avian influenza in migrating water fowl or the pathogen burdens of anadromous or catanadromous fish, it is clear that it is better to avoid, or at least significantly reduce, the risk of a disease outbreak occurring in the first instance rather than trying to eradicate a disease after an accidental introduction or outbreak has occurred.

2.1 Define what we mean by Avoid

In an ideal world avoiding disease and disease introductions would be the norm, pathogens could be kept out of a farm or the local environment by the use of appropriate biosecurity measures and farm animals would never encounter a pathogen during a production cycle. However, in the real world this is much harder to achieve as the animals and farm have to interact with the local environment and the ability to avoid pathogens entering aquaculture facilities are limited (as discussed in section 2.6). Making a facility, whether in netpens or in labs, completely pathogen free is often very difficult and usually economically unpractical for commercial purposes. It would require making a site completely biosecure, through the use of fully disinfected water entering the site, sterilizing all discharges from the site and fully training all staff in containment measures and biosecurity practices. What is achievable is a substantial degree of risk reduction by the judicious use of biosecurity measures and effective risk reduction strategies. Although it may not be possible to avoid all disease interactions on an aquaculture site, it is possible to reduce the risk from some diseases that can have a devastating effect on wild and farmed population. In some cases, by the judicious use of risk management strategies it is quite possible to have a biosecure site where it is possible to achieve specific pathogens free status.

To a certain extent this has been successfully achieved in some branches of terrestrial farming such as chicken or pig production where large centralized farms hold the disease free broodstock lines from which specific pathogen free offspring are sent to biosecure units for on growing. Some countries have attempted centralization of Broodstock for aquaculture (e.g. Maine USA [USDA 2003]) initially for genetic improvement, however the provision of SPF stocks from these breeding programs is at an early stage.

The word “avoid” can mean to ‘stay clear of or to prevent the occurrence of.” When it is applied to diseases, there are many level of avoidance. It can be taken to mean we avoid fish being exposed to some or all pathogens. It may mean we have procedures in place that prevent those exposures from becoming diseases. It may mean we stay clear of the economic or trade implications of that disease. In this section, we will be concerned mostly with the first of these definitions; the avoidance of exposure to pathogens.

2.2 Different avoidance Scenarios

Avoiding disease is a very difficult area to define from the point of view of an aquaculture environment, by far the easiest way to achieve this would be to house all aquaculture activity in biosecure units where the interaction with the environment, staff, wild and feral animals is strictly controlled.

In the recent OATA biosecurity document (Davenport and Bricknell 2006) it is stated *“Livestock will always be at risk from new and emerging diseases, even as current problems are overcome. Proactive farm health planning will help the livestock industry as a whole move forward.” This report and the suggestions contained in it will contribute to health plans relevant to our industry devised by individual businesses (exporters, farmers, importers, wholesalers and retailers) seeking to ensure, as far as they are able, the health of livestock upon which our industry depends.”* Clearly indicating that disease risk assessment strategy is required to be developed at both national, regional and farm levels to avoid outbreaks of serious aquatic diseases or avoid the introduction of exotic disease into an ecosystem.

2.2.1 National disease avoidance strategies

It is possible for individual nations to set avoidance strategies either at the national or regional levels. National controls may require disease or health certification from the competent authority stating that the population the animal came from have been pathogens tested and are specific disease free prior to an import permit being granted prior to importation. Some countries may impose quarantine procedures for certain fish species prior to their release in the aquaculture (or ornamental) industry as an additional guarantee. Within countries certain regions may have additional controls on importing aquatic animals from other regions within that country as an additional biosecurity measure. For example the state of Maine (USA) does not permit the importation of live bait fish into the state for biosecurity reasons.

Nations conducting trans-national fish movements often follow international standards for testing and control of certain diseases, especially those listed by the World Organization for Animal health (OIE). Because trade decisions often rest on the outcome of these tests, they are often undertaken at certified laboratories, ensuring a high level of laboratory quality assurance. The same can be said for many nations for within-country movement; recognized laboratories and diagnosticians must attest to the health status of fish groups before they are moved. There is, however, variation in the application of these requirements depending on the nation, region, and species involved. While Maine, for example, may preclude the movement of baitfish, there are many other jurisdictions within the USA that do not.

2.2.2 Endemic in the region but not on your farm

In a region (or country) that has an endemic disease established across the region it is possible that an individual farm may be able to eradicate that disease and maintain a disease free status. For example, during the recent outbreak of Viral Haemorrhagic Septicaemia (VHS) in England (2006,) in accordance with the EU Commission Decision 2007/345/EC, lists of approved zones and approved farms with regard to this disease were established. For farms that were located in the disease zone and wished to obtain “approved farm status” the regime, initial testing was established to determine the presence or absence of the disease. If the pathogen was present then an eradication program had to be established. If the disease was absent then the farm must instigate good biosecurity measures to ensure the pathogen wasn't introduced via environmental contamination or via new stock (which means the farm must instigate a certification regime by the countries' competent authority). It must also arrange for appropriate annual testing to be carried out again by a competent authority to ensure the farm is free of this pathogen. Often the testing regime requires a higher level of testing than the normal national testing regime, often quarterly, for 3-5 years to demonstrate absence of the pathogen of concern. After the intensive testing period has finished to maintain the approve farm status then it is normal for the farm to resume the standard annual testing regime for the region/country. To maintain approved zone status (areas where VHS was not found), farms in the disease free zone had to submit to annual testing for the pathogen.

Such regimes have been very successful in establishing approved farm status in countries such as Norway for ISAV permitting smolt and egg exports to the UK and Chile for example.

2.2.3 Endemic in the Country but not in the Region

It is possible for a region within a country to have a different disease status than other parts of the country. Geographic or ecological conditions may not be conducive to the introduction and establishment of some pathogens. Regional disease control measures might be more intensive or successful in certain parts of a country. In this scenario it is possible for a region to be declared free of a specific disease that may be widely distributed elsewhere.

The regional disease free status is maintained by routine annual testing of farmed and wild populations of the animals. Usually the testing is quite intensive initially to establish that the region is free of the disease of concern for a specific period of time and then reverting back to the countries standard disease testing regime to ensure that the specific disease free status is maintained on the farms and in susceptible wild populations. The OIE has established criteria for surveillance, regional disease history and testing that must be met in order to call an area free from disease.

New stocks of animals that are required for aquaculture can be moved within the zone freely (assuming that the regional and local legislative requirements for movements in the zone are met). When there is a request for movement of animals from without the zone in the approved zone then these animals must come from a country or region free of the disease with appropriate certification form the competent authority. A similar status can exist for a farm with approved zone status and providing that the approved farm meets the same health standard and testing/certification regimes of the region the animals are being moved to then the trade should be permitted.

2.2.4 Exotic Diseases that are known elsewhere

It is possible that a country is free of an exotic disease that is known elsewhere in the world. For example *Gyrodactylus salaris* is of considerable concern to wild and farmed salmon stakeholders in Northern Europe. This parasite has been introduced into Norway where its control has had a considerable impact on wild salmon stock in infected rivers but remains absent from Ireland, Great Britain and Iceland and virulent strains have been recorded in France, Italy and Spain. There have been considerable activity and surveillance programs in countries free of *G. salaris* to ensure that the parasite is absent (this is made particularly difficult as the parasite is morphologically almost identical to *G. thymalli* and molecular identification requires a degree of genetic sequencing. Indeed some authorities (Hansen 2003) have proposed that *G. salaris* is a virulent form of *G. thymalli* and that there is a *salaris*/*thymalli* species complex).

So the problem for countries that are free of certain diseases is how do they maintain their disease free status? One option is restricting or banning imports of fish from countries with the disease. However, international trade rules allow for the export of fish from approved farms or disease free zones within an affected country. The disease free country may require additional guarantees to prevent imports from disease free zones or “approved farm status” farms. Indeed such constraints imposed by disease issues have been considered by GATT and other free trade international agreements and must be considered when restricting trade in aquatic animals between states to prevent a conflict between free trade and state biosecurity occurring. However, to ensure that the disease free country remains disease free, that country must have an active surveillance program and have contingency plans ready to eradicate an outbreak of the disease should an accidental introduction occur. In Norway, *G. salaris* has devastated some stocks of wild Atlantic salmon (Paisley 1999) after it was accidentally introduced with Baltic salmon population which are resistant to the parasite. *Gyrodactylus* *salaris* has since been controlled in Norway by using rotenone to cull the entire fish populations in 23 rivers. However, it has also had a considerable impact on trade between the salmon farming industries of *G. salaris* free countries such as the UK where the presence of this parasite been a significant trade barrier.

2.3 What must be in place to avoid a Disease?

Disease avoidance is dependent on many practices these include a strong legislative framework in the country or province, the availability of excellent diagnostic services, good biosecurity measures on the farm, and appropriate risk assessment analysis. It is a truism that if a pathogen is not present in a country or region or on an individual fish producer's site it cannot be spread to a new site. Many countries require that imports are free of specific pathogens. To achieve this, different standards are incorporated in their import laws. There are lessons to be learnt from some of the model conditions established in these laws.

It is likely that as more Governments become more aware about biosecurity issues, that legislation will increase and new laws introduced with the aim of keeping fish diseases out. In a few instances there might be a relaxation of excessively tight regulation to avoid international action for imposing unfair controls through bodies like the WTO. However, rules on the national and international transfer of live aquatic (or indeed any) animals and plants are more likely to be gradually tightened than relaxed over the next few decades.

2.3.1a Herd and Individual Immunity

Immunological protection of an animal depends on two factors, individual immunity (how an individual within a population is protected against a disease) and herd immunity (the resistance of a group to invasion and spread of an infectious agent due to the resistance to infection in a proportion of individual members of the group).

2.3.1b Individual Immunity

In general, an individual can become immune by two main ways; (1) it can receive an effective vaccine or (2) it survives an infection with the pathogen. Both of these methods can ensure a protection against that disease; in some cases, that protection may be lifelong, where as in others, re-exposure/ revaccination is required. If an individual is lucky enough to survive the initial infection then a combination of memory cells and circulating antibodies provide protection against future disease. A similar thing occurs when one is vaccinated; the vaccine triggers the protective mechanisms of the immune system to produce the antibodies and memory cells required to provide protection. The major advantage of the vaccine is that there are very few deaths (ideally none) post vaccination compared to an individual being exposed to the virulent pathogen. See section 3.1.2 on details of the application of vaccination as an important disease control tool in salmon farming.

2.3.1c Herd (population) Immunity

Herd immunity relies on a proportion of a population being immune through either vaccination or exposure and the proportion of the protected individual in that population being sufficiently high that even if an unprotected member of that population got the disease chances are any individuals that came in contact with the infected individual would be immune and the disease could not spread. For example, if animal A is infected with a pathogen and subsequently exposed animal B which had been immunized against that disease, animal B would not succumb and hence when animal B comes into contact with animal C, B cannot pass on the disease to animal C. Even if animal C is susceptible to the pathogen, it indirectly gets protection from the disease. Hence good herd immunity will reduce the spread of pathogen in a population by protecting the vulnerable, susceptible, subgroup. The main issue with this method is only a small proportion of the herd (population) can remain susceptible for this method to be effective and that levels varies with disease e.g. in people 85% of the population must be immune against Diphtheria for herd immunity to be effective but only 75% need to be protected for good herd immunity to exist against mumps. The degree of herd protection required in aquaculture environments has yet to be determined.

2.3.1d Stress and Disease

Stress and disease in aquaculture is poorly understood, there are many anecdotal and grey literature articles that state “conclusively” that stress can lead to disease outbreaks. However, when the peer reviewed literature is examined the picture is very confused. As a rule of thumb acutely stressed fish tend to be immunostimulated rather than immunosuppressed. That is stress responses that are not induced by the cortical steroids tend to up regulate non specific defense mechanisms.

The picture is not so clear with fish that present long term elevated corticosteroids from chronic stress. Often chronically stressed fish arise from high stocking densities. The reason for the elevated corticosteroid levels is often suggested as being due to hierarchical interactions and dominance disputes and under such conditions these fish are more susceptible to infection. However, what is frequently not taken in to account is the function of the immune system and the dynamics of the pathogen under high stocking densities. When immune parameters are measured in fish with elevated cortical steroid levels no significant difference is seen between immune function in stressed and unstressed fish, demonstrating that these fish immune systems are not functioning at a lesser level than their unstressed compatriots. However, these animals often have elevated levels of infection. Why? There are several possible explanations. Under high stocking densities the disease dynamics may be optimized for the transmission of the pathogen between individuals due to physical contact, increased shedding rate, optimum water conditions, or increased breaches in the integument due to intra-species aggression. What is clear is that chronically stressed fish may present with a higher frequency of infection more likely due to the result of their interaction with the environment that causes the stress rather than as a direct response of the corticosteroid hormones.

2.3.2a Preventing Exposure

In an aquaculture setting, preventing the introduction and movement of disease causing agents is the cornerstone of disease prevention. The aim is to stop the pathogens entering the country, region or farm. It can also include the precaution need to prevent the entry of exotic species that may have an adverse effect on indigenous species or ecosystems or controlling or eradicating endemic problems.

2.3.2b Legislation

The legislative framework is dealt with in more detail in section 5 however if is suffice to say that the country in which an aquaculture farm is operating must comply with the legislative framework of the state to prevent the accidental importation of animals that may be carrying or infected with a disease exotic to that country. It is also required that the farm be inspected on an annual basis for the presence, or absence of notifiable diseases to ensure the farm is specific disease free. Policies and guidelines (both legislated and corporate) also govern the movements of fish within and between farms in order to reduce the movement of pathogens. For example, fish licensing requirements in British Columbia require a group's disease history to be considered when transporting fish.

2.3.2c Physical barriers

Physical barriers are a very effective biosecurity measures reception zones, gates and fences, all have an important role to play in preventing disease entry onto a farm or into a country or region. The first reception area when aquatic animals are imported should be the countries' customs to ensure the health certification and paper work and the competent aquatic animal health authority who grant import permits.

Land based farms should be protected by fences and gate to ensure that the general public do not have easy access to the grounds. Marine sites are harder to control access to. However a reception area and the use of the companies own boats, equipment, personal protective equipment, disinfection foot baths etc must be used when people access the site to ensure that the farm complies with the local biosecurity requirements (See chapter 4 and 5 for more details).

2.3.2d Disinfections

The disinfection of equipment, staff and visitors to a fish farm is an essential biosecurity measure. However, it is beyond the scope of this document to detail all of the chemical methods available to achieve this. Rather, it is proposed to outline the basic steps required to achieve biosecurity by disinfection.

The disinfection of equipment within and between sites is a fundamental procedure that needs to be carried out. This may be a simple as ensuring vehicles such as cars and boats are washed down with a suitable disinfection spray between sites or in the case of diving equipment (identified a as major risk factor during the 1998 UK ISAV outbreak) where immersion in a powerful disinfect for a prolonged period may be more appropriate. However, it is often appropriate for each farm to have its own equipment which is routinely disinfected after use rather than transfer it between sites. Only key equipment such a well boats should be permitted to transfer animals between sites and only then after a full risk analysis/risk identification exercise has been carried out.

Staff present different biosecurity issues. They can become complacent with biosecurity procedures such as hand washing and the used of dedicated personal protective equipment for certain area/sites. Although it is easy to have a biosecurity framework in place it is essential it is enforced through training and reinforcement to maintain good working practices. This latter point cannot be under emphasized as past disease outbreaks, including infectious hematopoietic necrosis virus outbreaks in British Columbia, have been traced back to lapses or gaps in biosecurity and disinfection. It is for this reason that the BC government has offered ongoing farm education before, during and after disease incidents to re-enforce biosecurity lessons.

2.3.2e Protected Environments

Direct immersion in the water provides sufficient opportunity for exposure to waterborne pathogens. Pathogens can potentially arrive through interaction with wild fish or transfer via other vectors such as birds. Even with the best biosecurity measure possible fish farms are still vulnerable to bio-terrorism such as the introduction of WSSV to a penaeid shrimp farm in Hawaii by a disgruntled employee.

It is much easier to protect shore-based fish farms where water is fed into the farm from a defined source. This can be achieved by ensuring the water supply is from a pathogen free source e.g. a deep borehole, or is treated by UV and/or ozone prior to use to eradicate any pathogens present in the environment. On marine sites, netting can be used to reduce direct contact with larger marine species as well as maintain the farmed fish within their pens. Selection of sites for marine farms do, in Canada for example, take into consideration of the suitability of the local environment for other marine species as well as the local oceanographic conditions. These can provide some form of indirect protection. In all forms of food production, it is nearly impossible to escape exposure to the environment and still produce affordable food items. As such, protection from environmental hazards is often a form of risk reduction, rather than complete exclusion.

2.3.2f Quarantine

Quarantine refers to the complete isolation of infected groups to prevent the group from exposing others to pathogens. It is most easily achieved if one only considers isolating one farm from another for a specific length of time. It may be impossible to achieve when one considers isolating farmed fish in a netpen infected with a waterborne pathogen from wild fish nearby. The lack of quarantine facilities large enough to accommodate commercial fish farms prevents one from moving infected fish to another location for quarantine. However, smaller quarantine facilities can be used to isolated smaller groups of imported fish. Although quarantine may be impractical from a large marine farm, when new species are brought into aquaculture it is wise to quarantine the wild caught broodstock and carry out a health screening to ensure that the potential new broodstock animals are not carrying disease asymptomatically or that can be transmitted vertically. One issue here in the diagnosis of fish diseases which often relies on destructive sampling and here is a need to develop and verify non destructive tests acceptable to institutions such as the OIE for fish.

2.3.3 Knowledge on what might be coming

The key to anticipating which diseases may affect a farm, region or country in the future is monitoring and reporting disease trends and emergence of disease to both the national disease surveillance competent authorities and international ones such as the OIE (see Chapter 5). Companies and governments have significant disease monitoring and surveillance programs in place that require examination of dead and sick fish, prompt investigation of unusual disease occurrences and regular communication of findings. Historically, the proprietary nature of salmon farming resulted in a lack of transparency with respect to reporting disease status. This has lead to some mistrust of government and industry reports. Steps have been taken to increase this trust, but there is not an international standard for reporting diseases. Despite this, access to information on fish health status for health managers (private and government) has improved in recent years and has improved capacity to be prepared for disease threats outside of a farm, region or nation.

2.4 Prediction – knowing what to avoid

2.4.1. Availability of Adult Salmon Increases Disease Detection

The early days of salmon farming provided a seemingly endless supply of new challenges for fish health managers. Adult salmon had rarely been accessible for their entire lifecycle prior to the salmon farming industry. As such, adult salmon at sea were not often examined for diseases or other health outcomes. It was hard, therefore, to predict what disease would come next. The industry was learning as it developed. This situation was not dissimilar to the experience of the alternative livestock and game farming industries or for wildlife health research. Keeping populations under increased scrutiny at the same time as holding them in captivity increased the likelihood of detecting new (or more often newly recognizing) health issues.

It is reasonable to assume that future changes to the way we house and rear salmon throughout their lifecycle will change epidemiological conditions and opportunities to detect disease and thus change observed disease patterns. For example, it can be expected that shifts to onshore tank-based rearing of adults would not only change opportunities for diseases to spread or be maintained but also the way we could observe those fish and, therefore, the types of diseases we might see. Changes in management strategies will also change disease patterns. For example, increased use of vaccines resulted in the description of new syndromes related to post-vaccination pathology in some species for some vaccines. The shift from raw food diets to processed feeds in the very early days of salmon farming worked to eliminate some diseases that were spread via the feed, such as marine tuberculosis. As the industry evolves, it can be expected that disease patterns will change with some diseases disappearing while others emerge. Disease-free salmon farming will remain an elusive and impractical goal for the foreseeable future. These predictions are based on experience with land based agriculture.

2.4.2 Prediction of Specific Outbreaks

Epidemiologists have been working to predict infectious diseases in people and animals for centuries, most often with the goal of predicting the timing and size of outbreaks. Most epidemiologists will admit though that accurate predictions of the details of “who, what, where, when and how much” for disease outbreaks is notoriously difficult to achieve. Without doubt we can recognize conditions that are conducive to outbreaks of disease in general. It is almost common knowledge that, whether we look at fish, people or pigs, factors such as poor nutrition, inadequate biosecurity, and crowding are all factors predisposing for disease outbreaks. But predisposition does not mean predetermination. Not all crowded populations experience outbreaks, for example. Our predictive capacity is somewhat better for endemic diseases for which we have a number of years of experience. In some cases, specific variable serve as predictors (or risk factors) for specific diseases. For example, high rates of chronic inflammatory conditions on a farm were predictive of the occurrence of plasmacytoid leukemia in farmed Chinook salmon in Canada (Stephen and Ribble 2005). High water temperatures were historically times of increased risk for vibriosis in farmed Pacific salmon in British Columbia while low temperatures have been linked to outbreaks of flexibacter infections in hatcheries. Fish health managers incorporate the knowledge of such husbandry and environmental risk factors when developing disease prevention or control strategies. Unfortunately, the significant effects of local variables (such as population contact networks and environmental conditions), pathogen-specific variables, and chance (stochastic) factors place fundamental limits on our capacity to predict the course of a newly described infection or even to forecast the extent of an outbreak of known pathogens with reasonable degrees of accuracy. Therefore, prediction of outbreaks become matters of probabilities rather than certainties and fish health managers can reasonably be cautious when trying to forecast those conditions that will/will not result in disease outbreaks.

There has been a historic bias towards interest in predicting and preventing infectious and parasitic diseases of salmon for three main reasons: (1) infectious diseases have routinely been diagnosed as a cause of significant levels of death and disease in farmed fish; (2) concerns about transmissibility outside of infectious diseases to wild fish and; (3) bias toward infectious disease in animal health legislation and trade regulations. It can be anticipated however, that as the industry matures, it will follow the course of other food animal systems and non-infectious disease issues will increase in number and significance for salmon farmers. Regardless of this prediction, we can also assume that new infectious diseases will continue to be found. It was estimated in the early 1990's that less than 2% of fish diseases are known, and our understanding of the known diseases is incomplete (Stewart 1991). While more diseases have been recognized since then, most often associated with aquaculture settings, more continue to be discovered, suggesting we have yet to reveal the full complement of fish diseases present in natural or farmed systems.

A tremendous challenge that will confront us in the future is how to interpret the finding new patterns of disease in wild fish. There is a tendency to assume that if a disease was first described in farmed fish and subsequently found in wild fish, the farmed fish was the sources. The 1997 Salmon Aquaculture Review in British Columbia concluded that, at the time, no infectious agent found in farmed fish were unique to farmed fish and most were present in wild fish before the establishment of the industry (Stephen and Iwama 1997). The probability of finding new diseases in wild fish will increase once wild fish are subject to more surveillance, disease surveys and research. We lack the ability to forecast which of those diseases might be significant because of all of the ecological uncertainties described above. Only a small number of diseases currently have been associated with widespread, conspicuous epidemics in wild populations. This most likely reflects the fact that significant disease problems in wild populations go unnoticed or unrecorded or that some of the pathogens involved are opportunists in compromised populations, rather than a reflection of the true prevalence and impacts of pathogens in wild environments. This is particularly true for chronic parasitic infections that do not result in mass mortalities (Kent & Fournie, 1993).

There is emerging evidence that disease exists and results in population regulating effects in wild fish in sub-clinical forms that would not be apparent to surveillance methods that rely on morbidity or mortality events to trigger investigation or for those that use clinically detectable pathological lesions as surveillance case definitions. Because the vast majority of the literature on fish pathogens has focused on the effects of disease at the individual, organ or cellular level, risk assessments have frequently focused on mortality and morbidity as the principle impacts of concern, especially as they may influence trade. Very little work has been done on individual variation to pathogen exposure, particularly in terms of sub-clinical impacts because most fish diagnostic methods require fish to be killed to collect diagnostic material. This trend is changing as researchers begin to look at variables such as impacts on swimming performance or growth rates in response to infections. When we couple the lack of similar sub-clinical data with the compounding effects of other environmental and human impacts on wild fishes, predicting with specificity the local and regional effects of specific infections on wild fish becomes complicated and potentially unreliable.

2.4.3 Communication across other farms and regions – what is next door?

One factor that can increase our ability to predict which diseases we need to think about is the knowledge of what is affecting our neighbors. In the case of risks to local wild fish populations, knowledge about the disease status of a local farm is informative. Some jurisdictions have moved towards regular mandatory reporting of diseases on farms. The fish health auditing and surveillance program in British Columbia is a provincial program that includes active surveillance using provincial staff to inspect farm sites and collect specimens for health evaluation Sampling is aimed at achieving a 95% confidence for detection of 2% disease incidence. This is complemented with a private-public partnership known as the BC Salmon Farmers Association Fish Health Database. It was designed to improve access to and information on the health of all cultured fish stocks in British Columbia. The database is a privately operated system which will amalgamate fish health information from private aquaculture facilities and federal and provincial fish enhancement programs. These two efforts significantly improve government and industry understanding of disease trends and emerging risks. It is not, however, yet available to the public on a farm-by-farm basis due to concerns over privacy of information. Regional summaries are provided on a quarterly basis. These mandatory and voluntary report systems are a significant improvement over the state of communications that existed in the early 1990's where companies were reluctant to share information between each other so as to gain competitive advantages. Lessons from diseases such as infectious hematopoietic necrosis taught farmers in that province that failure to share information on diseases with their neighbors often doomed them to uncontrollable disease outbreaks.

Nations are also required to inform each other about their disease status. Member nations of the World Animal Health organization (OIE) are obliged to report specific diseases to ensure transparency of the world animal health situation. Historically, reporting to the OIE was required only for specific named diseases. In recent years, the OIE has required countries also report important epidemiological events. For aquatic animals, this includes; the first occurrence or the re-occurrence of an OIE-listed disease in a country or zone/compartment of the country previously considered to be free of the disease; any occurrence of an OIE-listed disease in a new host species; any occurrence of an OIE-listed disease caused by a new strain of the pathogen or in a new disease manifestation; any occurrence of an OIE-listed disease, if the disease has newly recognized zoonotic potential; and/or any occurrence of an emerging disease or pathogenic agent if the event is of epidemiological significance to other countries. (http://www.oie.int/eng/info/en_info.htm?e1d5). Reports to the OIE are available for public viewing, but not at a farm-by-farm basis. While OIE information helps in preventing the movement of pathogens between countries or zones within a country, they are not as informative for local assessment of risks to wild species from the local salmon farming industry.

A third mechanism for sharing information on neighbors' disease status arises due to the multinational nature of the salmon farming industry. Companies often operate in more than one country and at time are involved with rearing more than one species. Observations of change disease status and health risks can be rapidly disseminated internationally through internal communications. The proprietary nature of thee communications can, at times, limit the value of such information. Critics of the salmon farming industry often state that the proprietary nature of many of the surveillance mechanisms for salmon farming prevents transparent assessment or prediction of risks to local fish populations. However, it is not only the lack of disease data that limits predictive capacity. Lack of the incorporation of local ecological data or information on fish physiology also limits the capacity to predict the effects of diseases from salmon farms on wild fish. Improved mechanism for sharing and incorporating the complexity and diversity of information required to model and predict disease outbreaks should be a focus of future fish health research.

2.5 Promoting Resistance

Disease prevention can be achieved by many methods by far the easiest is good biosecurity and outlined in section 2.3.2. However, overall improved resistance to disease can be achieved by many other methods such as selective breeding programs where disease resistance traits are selected for, genetic engineering where disease resistance genes from one species are incorporated into the genome of the recipient species or by the use immunoprophylaxis (vaccines and immunostimulants).

Selective breeding programs have been practiced for many years in terrestrial agriculture systems leaving to many strains of the common domestic animals we see today. Indeed some of these strains be them, heritage or modern, have had genes from disease resistant families incorporated into them to improve the bloodline. This has often led to local varieties being developed which as suited to the local biotype. However, salmon have only been commercially cultured for 30 years compared to more than 3,000 years that sheep and goats have been domesticated. So it is not surprising that the selective breeding programs for fish are not as well developed as they are for terrestrial agricultural systems. Clearly there is considerable opportunity to develop improved bloodlines for farmed fish and there has been considerable investment in this by some governments (e.g. USA for ISAV resistance and improved farmed catfish lines) and commercial ventures e.g. (UK and Norway for IPNV).

Genetic engineering that is intended to incorporate genes form species resistant to a pathogen into a new species has many problems. Although technically feasible there is huge public resistance to genetically engineered food entering the food chain in Europe and North America. So much so that the early genetically modified fish programs have been abandoned and, at the time of writing, the salmon aquaculture dialogue group is not aware of a research or commercial program that is actively researching the field.

2.5.1 Specific prevention of infection

Immunoprophylaxis has been practiced for almost 225 years since Jenner's work of 1796 and is a well established method of disease control having had tremendous successes in eradicating, controlling or minimizing the impacts of diseases in people and domestic animals. In Atlantic salmon aquaculture, the first successful vaccine against *Aeromonas salmonicida,* developed in Scotland, effectively eradicated the disease from fish farming. This vaccine and subsequent ones developed in Norway and Canada have revolutionized the use of antibiotics in Atlantic salmon farming, almost eliminating their use in farmed salmon production. Vibrio vaccines in BC also significant reduced the need for antibiotics as they effectively reduced this disease in cultured Pacific salmon.

The duration of the protection induced by a vaccine can often be an issue. There is a dogma that fish adjuvants required powerful oil based adjuvants (Midtlyng, 1997; Midtlyng, Lillehaug, 1998) however there is strong evidence that long term protection can be induced by well designed vaccine without requiring oil based adjuvants (Bricknell, Ellis, 1993; Bricknell, Bowden, Lomax, Ellis, 1997; Bricknell, King, Bowden, Ellis, 1999; O'Dowd, Bricknell, Secombes, Ellis, 1999; Vipond, Bricknell, Durant, Bowden, Ellis, Smith, MacIntyre, 1998). Certainly powerful adjuvants can improve the performance of vaccines where the protective epitopes have not been well characterized or there are issue with immunogenicity of the antigens, but these oil adjuvants have adverse side effects in Atlantic salmon such as granuloma formation and adhesions and are required to be phased out of use in animal vaccines under current EU legislation (Council Directive 92/40/CE).

The greatest challenge for fish vaccination remains the viral diseases and parasites. There have been significant advances in protecting fish against viral diseases such as VHSV, IPNV and IHV often by using inactivated, whole virus vaccines, DNA, sub-unit vaccines or recombinant protein vaccine technology. In other cases, the capacity for some types of viruses to readily mutate, mix or re-assort their genetic material means that the antigenic structures of different strains of the virus can quickly change, making it hard for a single vaccine to cover all strains.

Vaccines against fish parasite have remained elusive, indeed effective parasite vaccines have remained elusive for higher vertebrates too. The major parasite problem affecting Atlantic salmon farms continues to be sea lice either *Lepeoptheirus salmonis* in the northern hemisphere or *Caligus rogercresseyi* in South America. The problem with most ectoparasites such as sea lice is they are not true blood feeding animals in the same sense that ticks or hookworms are, both of which have been the subject of successful vaccine research programs. A blood based diet permits large amounts of neutralizing antibodies to penetrate the parasite and damage it. Instead sea lice graze on the surface of the fish eating a mixture of mucus, skin, dead tissue and drinking seawater for osmoregulation purposes. Blood is rarely taken and when it is it is at the end stages of the disease when open lesions have developed. Such an environment in the sea lice gut is potentially hostile to any antibodies and other defense proteins that are ingested as the parasite feeds. It has been said that developing a vaccine against sea lice is a bit like trying to vaccinate antelope against lions, the antelope develop very good antibody titres but the lions still eat the antelope, antibodies or not. So it is quite feasible that a successful vaccine against the gut of adult sea lice may never be developed due to the hostile environment that the antibodies are expected to function under.

2.5.2 Non-specific prevention of infection

There are many ways a fish's immune system can be non-specifically promoted. Simple anatomical features like scales can provide physical barriers to infection agents. Non specific prevention of infection can be achieved by the use of good biosecurity measures. There are also dietary components or drugs that have been found to non-specifically bolster protection against disease, hereafter referred to as immunostimulants. Immunostimulants, often presented to fish as a dietary supplement, are a group of compounds that active innate defense mechanisms without the presence of an antigen or the associated invading pathogen. There are many compounds that fall into this category but many of them possess repeated molecular sub-units that mimic the molecular patterns associated with the surface of a pathogen (see Bricknell & Dalmo 2005). It is these pathogen associated molecular patterns, or PAMPs, that trigger the immune system into mounting a response against these compounds and this has been used for many years in both terrestrial agriculture and aquaculture to up-regulate an animal's immune response prior to a stressful event such as shipping or grading.

Immunostimulants are not the complete disease panacea. Their effectiveness is affected by the dose of the pathogen challenge to the fish, the nature of the disease, and the presence of other stressors or disease risk factors. While they provide protection from a disease establishing itself, this tends to be a short term response compared to a vaccine and if they are consistently presented to a population of animals there is the risk that tolerance will be induced. So for them to be effective they are best fed in pulses, for fish this is typically 6 weeks on the immunostimulant followed by six weeks with no immunostimulant in the diet and this is then repeated cyclically. Immunostimulants also have the potential to protect larval fish from disease before their adaptive immune systems are sufficiently mature to provide specific defenses. However, great care must be used when administering immunostimulants to larval fish as there is unknown risk of damage to the developing immune system.

2.6 Preventing Transmission

Section 2.3.2 discussed preventing exposure from a regional and national biosecurity point of view; however one aspect that has to be considered is how diseases spread between animals within a fish farm and between fish pens and associated sites.

2.6.1 To, Within, and Between Farms

As discussed briefly when new animals are bought into an aquaculture site there is a need to ensure that those animals are specific pathogen free (ideally pathogen free status would be desirable, but this is unlikely it be achieved under current husbandry methods, as is the case for most forms of animal agriculture). What is achievable is to ensure that the populations being brought onto the farm have been screened for pathogens of concern either by certified laboratories or by government, or state laboratories, to ensure that they are free of the major pathogens of concern.

The movement of animals between grow out sites is a difficult area, this is especially true when new broodstock populations as these are often moved to a new location. Ideally the movement of fish from one grow out site to another should be avoided because of the risk of transferring any disease they have picked up in the primary area to the new site (this is especially true it the population is being split as both the old farm and receiving farm will now have the pathogen). Usually states have legislation in place to monitor site to site movements and this legislation may require health screening prior to the movement taking place and may not be permitted if movement restriction have been in place to prevent the movement of populations that have been exposed to notifiable diseases.

Boats and other sea going craft have been indicated as potential fomites. For example Scottish legislation requires that if a well-boat is used to transport the fish the valves must be closed to prevent water exchange within 5 km of a fish farm. After transfer the well-boat should be dry-docked and disinfected before any other operations are carried out, such as transferring smolts or grading. This is particularly important when animals are being shipped to a processing plant for slaughter as there is a temptation for a well boat to make ‘bus stop’ deliveries during this type of shipping (and indeed during smolt deliveries).

Once harvest size fish have been shipped to a processing plant there is the issue of what to do with the waste products such as blood and offal. It goes without saying that the slaughter of fish should be carried out under conditions of high containment with all blood and waste water from such activities being disinfected and disposed of in an approved manner (e.g. disinfected with ozone or hypochlorite prior to disposal). The fish racks and viscera are often shipped to rendering plants via road transport systems. The vehicles used for such transports should be sealed and thoroughly disinfected after use; the receiving rendering plant must be biosecure (in regard to vermin, leakage of material etc.) and during rendering the temperatures reached must be sufficiently high to inactivate any potential pathogens.

2.6.2a. Farm and Non-farm Interaction

A major concern in salmon, and other finfish, aquaculture is the interaction between farmed populations and wild populations. It is desirable to restrict the interaction between farmed and wild fish populations as it is highly likely that the wild fish will spread disease into the specific pathogens free farmed stack which will, in turn, have the potential to bio-magnify the pathogen and act as a disease reservoir. There are other health issues related to wild-farmed fish interaction, such as ecological competition and interbreeding, which are dealt with in other reports. The focus of this report will remain on the implications of such interactions on disease and disease impacts.

It is possible to restrict these interactions to a significant degree by considering the following mechanisms:

2.6.2b. Physical Barriers

If it is possible to isolate a farm by using physical barriers, such as placing a marine farm on land or inside a building, this could limit the interaction between farmed and wild fish; the degree of separation being dependent on water and waste management methods. It provides the opportunity to disinfect effluent to prevent the escape of pathogens into the environment as well as permitting the construction of physical barriers to prevent and escaped fish entering the local environment.

Such contained fish farms can also play an important role as quarantine centers when new fish stocks are bought if from another country. Indeed because of the isolated nature of these land based facilities, designed primarily to protect the farm stock from wild fish diseases, there is a secondary benefit of reducing the risk of either fish or disease 'escaping' from these farms.

2.6.2c. Geographical Barriers

An area that is gaining support is the location (and relocation) of fish farms away from areas of importance to wild fish. It is well known that many species of fish will associate themselves with a fish farm using the facility as a reef setting up territories and using them as a habitat or entering the cage itself when small enough to make use of the food resource being fed to the farmed fish. For example the relocation of salmon farms away from the migratory path of salmon smolts has considerable support in some areas as it is believed (although the scientific evidence to date is somewhat circumstantial and more thoroughly addressed in the sea lice section since transmission of infectious diseases in general have not proven as critical to the site location issue) that the disease risk and impact of any escaped fish will be less if there is a considerable distance between wild and farmed stocks of the fish being farmed. Such risk reduction steps is reflected in siting legislation in some jurisdictions such as BC, Ireland, and in some Norwegian fjords. However it is worth bearing in mind that such relocations must be considered carefully as the fish farms must be locations that are economically viable and not so distant from the original range of the fish being farmed that the species would be considered exotic if an accidental escape occurred. Lastly, once the minimal proximity to other farms has been addressed, most jurisdictions have approached site location as primarily dealing with issues of conservation, nutrient-loading, and aesthetics, rather than disease transfer potential.

2.6.2d. Escapes

It cannot be contested that pathogens can be moved as fish move. The literature is full of reports where pathogens have crossed ecological boundaries and have become established in new areas due to the translocation of fish for commercial and fish enhancement purposes. This has led to the concern that if infected fish were to escape a netpen, they could carry pathogens with them. Whether these pathogens are exotic to a region or native pathogens that might exacerbate disease risks to native species, those advocating for greater risk reduction in salmon farming seek ways to prevent the movement of diseases outside of farms by way of escaped fish.

To prevent such problems occurring farms must take precautions to prevent escapes by the use of appropriately designed sea cages, raceways, tanks etc. and the farm must have a contingency plan in place to ensure that if an escape has occurred there is a procedure to recapture the escaped animals to minimize the impact to the local ecosystem. In some states (e.g. Scotland and Norway) legislation exists that if an escape of farmed animals occurs it has to be reported to the competent authority for a formal investigation of the incident and it is required by law that the farm from where the escape occurred recapture the escaped animals or face punitive fines.

Another area of escapes that may emerge as a significant issue is the releases of gametes or fertilized eggs into the environment. This is not an issue with farmed salmonids as they sexual maturation is closely monitored and occurs in freshwater.

Chapter 3: Disease prevention

3.1 What are the tools for prevention against infectious diseases?

There is no single tool that can be used to prevent, control or manage infectious diseases. Rather a program of different activities and methods are required to prevent exposure, prevent susceptibility and prevent the adverse effects of an infectious disease. The combination of vaccination and improved management practices proved successful in protecting fish against clinical outbreaks of many diseases. While 48500 kg of active ingredient (antibiotics and chemotherapeutics) was used for treatment of bacterial fish diseases in Norwegian aquaculture in 1987, the corresponding figure for 2006 was just above 1000 kg. The production volume increased 10-fold over the same time period. The reliance on a treatment approach, particularly the use of antibiotics has been significant reduced in aquaculture thanks to advances in disease prevention.

3.1.1 The immune system

In order to provide background to understand how vaccines work, we present an overview of the fish immune system. The immune system may be defined as the interaction of tissues, cells and soluble molecules whose primary function is to remove invading microorganisms that cause damage to the body. A major challenge of the immune system lies in the recognition of the invading pathogens (bacteria, viruses, fungi and parasites) and mounting an appropriate effector response. As the immune system also has the possibility to act on the organism itself, the responses need to be carefully regulated and balanced to avoid becoming harmful.

The most prominent macroscopic differences between mammalian and teleosts immune systems are the location and distribution of relevant cells, tissues and organs. The obvious differences are that fish lack bone marrow, lymph nodes and Peyer's patches. The kidney and spleen are major lymphoid organs in the teleosts in addition to the thymus and mucosa-associated lymphoid tissues (Koppang et al 2007, Press and Evensen 1999, Fletcher and Secombes 1999, Fange 1996, Kattari and Irwin 1985).

There are two fundamentally different forms of recognition of pathogens (or foreign antigens) by the immune system, and on this basis it is customary to classify the immune system into the innate (previously referred to as non-specific) and the adaptive immune systems (previously the specific immune system). Even if the immune system is divided in two entities, it is important to stress that the responses work together, and are mutually dependent on each other. The innate responses are mobilized rapidly and mediated by receptors that recognize common structures on microbes not found on the body's own cells. In contrast to the innate system where repeated exposure to a given infectious agent does not alter the responses, adaptive responses improve with successive encounter with the same pathogen (memory). Another important difference is that adaptive immune responses are highly specific for a particular antigen using antigen receptors only expressed on lymphocytes (specificity). The use of non-specific immune modulators as described in paragraph 3.1.4, stimulate primarily the innate immune responses while a classical vaccine will also induce adaptive responses.

Most multicellular organisms possess some form of innate immunity, but in contrast the adaptive immune system is restricted to vertebrates (Parish 2005). All fish possess innate immunity, but in addition they also exhibit the necessary antigen receptors (immunoglobulin and T-cell receptors), antigen presentation molecules (major histocompatibility complex - MHC) and gene rearranging proteins (RAG genes) needed to induce an adaptive response. As teleosts represent one of the first classes of animals that have developed adaptive responses, this makes teleosts particular interesting from an evolutionary point of view, and constitute the biological basis for vaccination of salmon. The two key features of the adaptive immune response are specificity and memory. Memory is provided by memory cells, being lymphocytes. Both memory B cells and memory T cells have been defined. They are more sensitive to antigen than are naïve lymphocytes and respond rapidly on re-exposure to the antigen that originally induced them (Janeway et al. 2005). Albeit indications of the existence of a memory in fish has been reported (Boudinot et al. 2001), it is not definitively proved. Long immunological memory in salmonids might be due to retention of antigens caused by oil-based adjuvants, selection of high affinity antibodies within the immune system, or continuous exposure of *Vibrio spp.* from water.

3.1.2 Vaccination

A sustainable development of salmon farming would not have been possible without vaccination against the major bacterial diseases. Keeping fish in a high density environment facilitates disease transmission to uninfected individuals. This makes control after outbreak difficult and underlines the need for prevention of disease rather than treatment.

In the early days of fish farming, significant effort was placed on treating diseases as opposed to prevention. For example, during the 1980s salmon farming in Norway experienced huge losses from bacterial diseases (mostly *Vibrio* spp.) and a total crash in the industry was only prevented by the use of vast amounts of antibiotics (Sommerset et al 2005). Ongoing heavy use of antibacterial drugs would have severely impacted both the economical basis of aquaculture and caused unacceptable influence on the environment (Berg 2006) . Moreover, the need to prevent death was seen as an important animal welfare issue.

This created the background for the development of vaccines and the solution came from the use of immersion vaccines based on formalin-inactivated broth cultures. They had earlier proven efficacious against vibriosis in USA in the 1970s (Evelyn 1997). In the early 1990s a new bacterial disease, furunculosis (*Aeromonas salmonicida* ssp*. salmonicida*) appeared in Norwegian salmon farming and caused a new epidemic the following 3-5 years. Furunculosis could not be prevented through the use of immersion vaccines and a new method of delivery was needed. Initial trials indicated that i.p. administration of formalin-inactivated bacterins containing aluminum salts as adjuvants gave a short term protection (Lillehaug et al 1992). A study by Midtlyng and co-workers concluded that oil adjuvanted furunculosis vaccines induced long-lasting protective immunity (Midtyling et al 1996). The same researchers also reported polyvalent vaccines gave superior immunity compared to monovalent vaccines, suggesting the effect of the furunculosis components to be enhanced by adding other bacterins, like *Vibrio spp*. The oil-based adjuvants allowed a prolonged release of antigens through a depot formation (Singh and O'Hagan 2003, Gudding et al. 1999, Navot et al. 2005)

Atlantic salmon in all salmon producing countries are vaccinated against bacterial and/or viral diseases relevant to the country/region were the fish are transferred to sea. Albeit vaccination in salmon aquaculture seems to efficiently prevent many bacterial diseases, the viral diseases are far from controlled by vaccination. Vaccines are available that will confer immunity against 6 different pathogens (e.g. multivalent vaccine may include 5 bacterial and 1 viral antigens), including *Vibrio anguillarum* (two serotypes), *Vibrio salmonicida* (cold water vibriosis), *Aeromonas salmonicida* ssp. *salmonicida* (furunculosis), and *Moritella viscosa* (winter ulcer). In addition some vaccines against IPN (caused by infectious pancreatic necrosis virus), pancreas disease (caused pancreas disease virus or salmonid alphavirus), IHN (caused by infectious hematopoietic necrosis virus), and ISA (caused by infectious salmon anemia virus) are available.

The viral vaccines are based on inactivated antigens (IPNv and ISAv), a recombinant subunit antigen (against IPN) or is delivered as a plasmid vaccine (against IHN in Canada). The vaccines are either delivered as an oil emulsions in the peritoneal cavity (IPN, PD, or ISA) or as a water-based solution injected intramuscularly (IHN plasmid-based vaccine). Immune responses generated from the use of non-replicating vaccines are skewed towards a humoral response (antibodies) usually effective in elimination of extracellular pathogens. These vaccines are usually of moderate efficacy against diseases that are caused by pathogens like viruses (Biering et al 2005).

Administration of vaccines to fish can in principle be done in following ways, by injection, by immersion, usually by dipping the fish in a diluted vaccine solution, or by oral administration (Gudding et al 1999). Parenteral administration, mainly intraperitoneal injection, is by far most common. Although this method is the most labor intensive and involves more handling of the fish, the level of protection is superior to the other routes. A major drawback is that fish have to be over a certain size (25-30g) before injection vaccination can take place. Immersion vaccines are effective against a number of bacterial pathogens, and can easily be administered to small fry. It requires large amounts of vaccine though, and the resulting protection is generally lower compared to intraperitoneal injection (Midtlyng 1996).

Oral vaccination with antigen included in the feed would be the ideal method of vaccine delivery to fish, and hence much research has focused on development of such vaccines. The main challenge is to protect the antigens from digestion and decomposition during passage through the stomach and anterior part of the gut to stimulate the immunocompetent tissues in the posterior part of the intestine (Gudding et al 1999). Furthermore, a large quantity is usually necessary, and the protection achieved is generally weak and of short duration (Sommerset 2005).

A point of concern is that even though vaccination of Atlantic salmon with oil-adjuvanted vaccines induces long-lasting protective immunity, it concurrently results in the formation of visible injection-site lesions (Midtlyng 1996). These lesions are characterized by granulomatous inflammation and melanin accumulation. They are recognized as adhesions between internal organs and between the organs and the peritoneal wall, but may as well affect different tissues and organs (Koppang et al. 2005, Mutoloki et al. 2004). Despite the strong responses at the injection site, considered as negative for fish welfare and flesh quality, these responses seem to be of pivotal importance for the long term protection from vaccines. Thus, the challenge is to maintain a balance between the cell reactions considered necessary for initiation of immune responses and at the same time to avoid tissue damage (Evensen *et al*, 2005).

Some of the future challenges for salmon aquaculture lie in the development of better vaccines, especially for intracellular pathogens like viruses. At the same time, focus should be set to reduce the side-effects caused by vaccines, by improving formulation as well as antigen purity and concentration (Evensen *et al*, 2005).

3.1.3 Licensing of Vaccines

Licensing of vaccines by governmental bodies is a lengthy process and requires in principle documentation of the quality of the product and all ingredients used for the manufacturing and documentation of the vaccine plus a safety and efficacy documentation in laboratory studies and through field trials. The safety of oil-adjuvanted vaccines is documented through acute toxicity plus by showing that minor local reactions are present over the economical life of the fish. Safety and efficacy are mandatory on every vaccine lot. In most jurisdictions, the field efficacy requires trials in a minimum of 2 premises on production animals. Post-marketing follow-up will allow the vaccine users to identify when vaccines work or don’t work under their specific conditions.

3.1.4 Non-specific Immune Modulators

Immune-stimulants are chemical compounds that activate the innate immune system (of fish) and hence may render animals more resistant to infections by viruses, bacteria, fungi and parasites. During evolution the immune system has developed mechanisms to detect chemical structures which are typical for potentially dangerous microorganisms and use those structures as *alarm signals* to switch on the defense against infections. In the presence of such chemical signals the immune system will respond as if exposed to or challenged by a pathogen. Hence, administration of an immune-stimulant prior to an infection may elevate the defense barriers of the animal and thus provide protection against an otherwise severe or lethal infection. The duration of the response is much shorter compared to what is obtained using a vaccination strategy. Most immune-stimulants are chemical compounds that are structural elements of bacteria, fungi or yeasts. There are also many synthetic compounds that have been found to possess immune-stimulating properties of fish and other animals.

Yet another feed supplement that is now listed under oral immunostimulatory compounds is the nucleotides. It is difficult to find good documentation that nucleotides results in immune enhancement but supplementing the normal levels of nucleotides present in the diet of the fish has shown improved differentiation and development of the cells of the intestinal tract. This is again seen as an advantageous effect of enhancing intestinal absorption of feed additives and pigmentation for coloring the flesh. It has been shown that dietary nucleotides exert a significant influence on many mammalian immunological and physiological functions and more specifically nucleic acid precursors are instrumental in the healthy differentiation and development of the cells of the intestinal tract. Studies (Burrels *et al*, 2001) have also shown that diets supplemented with nucleotides gave increased intestinal mass, gut wall thickness, accelerated mucosal repair and enhanced populations of gut micro flora. In mammalian species, it has been demonstrated that additional dietary nucleotides induce an increase in the height of the intestinal villi resulting in an overall expansion of the total mucosal surface area.

The need for nucleotides is viewed as being particularly important during periods of increased growth and/or renewal. DNA is duplicated during growth and every strand of DNA contains approximately three billion nucleotides. Most fish must produce millions of new cells every second just to maintain the status quo, it is easy to understand that during times of stress (growth, reproduction, environmental change or challenge, combating disease and recovery from injury) thousands of billions of additional nucleotides must be readily available for cell proliferation. However, since the organism must first produce these nucleotides, this continual process is slow and metabolically requiring. Most cells are capable at producing sufficient amounts of nucleotides to maintain a satisfactory supply to the organism for normal metabolic activities and life. For a healthy fish, this constant resupply of nucleotides is very well balanced and is appropriately adjusted in response to occasional stress. However, an increased production of nucleotides takes time and energy, and taxes the fish’s supply of basic raw materials to produce more nucleotides. The fish’s own production of nucleotides is based on average requirements, with allowances only for occasional short-term increase in response to growth, health challenge, and so on. For a fish to maintain good health, much depends on how quickly it can adapt to changing conditions. Only very few defense cells recognize these viral or bacterial invaders and move to combat them. It is thought that readily available building blocks will shorten the response time, allowing the body to initiate the fight against the infection at the initial stage of infection.

3.1.5 Genetics

In contrast with livestock and plant crops where improvements in production have been based on modern breeding approaches, there are relatively few examples of such programs for farmed fish; Atlantic salmon in Norway and the UK, Nile tilapia in Asia and channel catfish in the USA. However, principles of genetics can be applied to the farming of marine species to increase cost effectiveness through improved breeds. The application of such technologies can be divided into short-term or long-term improvement. Only long-term improvement will be described and is also described as selective breeding programs where small gains accumulate over generations. Recently, there has been a call for the use of genetic technologies that can reduce the risk of adverse environmental effects following escape of farmed salmon to the environment.

An important factor for a sustainable and efficient salmon farming industry was the implementation of breeding programs as early as in the beginning of the 1970s. By seven generations of selective breeding of salmon, the descendants grew twice as fast as their wild ancestors. Today we also have to add improved feed quality and better production conditions to the list of factors contributing to the changes observed. Additionally breeding goals like age at sexual maturation, resistance to disease, flesh color and body composition have been taken into the program at later stages (Gjedrem 1995). Although major advances in disease resistance (that do not sacrifice other important characteristics) through selective breeding has remained elusive, it is expected that at least moderate gains will be achieved over the coming decades.

3.1.6 Nutrition

Improved feed quality has contributed significantly to increased profitability in the farming industry over the last 20-25 years and has also made a contribution to the health and welfare of the fish. Over the last 10 years there has also been a major change in the fat content in the feed for salmon in Norway. In 1990 the fat content was 20%, increasing to more than 30% in 2000, declining to around 27-28% today. An interesting change is the ratio of fish oil of the total feed fat; 20% in 1995, 30% in 2000 while today the fish oil content has been reduced to 20%. It is foreseen that the percentage fish oil will decline even further over the next decade, the reason for this change being attributed to the increased price of fish oil and also an anticipated shortage in the world market over the next 20-25 years. These changes in sources of oils (e.g. moving from fish oil to vegetable oil) are not expected to have deleterious impacts on the nutritional health of the salmon. However, it remains to be seen if the composition may have any unforeseen effects on drug delivery or absorption and, thus, potentially change the control of disease.

3.2 Herd health & HAACP on farm

3.2.1 Herd health

The concept of herd health is a cornerstone of modern animal agriculture. There is ample evidence to show that strategic health management programs focused on disease prevention, health promotion and enhanced animal welfare can increase livestock productivity and efficiency far in excess of programs that focus on disease treatment. At it's simplest, herd health has the primary function of managing animal populations to ensure their capacity to withstand stresses from diseases and production conditions overwhelms the level of pathogen or stressors in their environment so that the animals do not become ill and the cost of production remains acceptable to farmers. In more recent years, herd health has incorporated programs that serve to reduce the environmental impacts and food safety risks from animal food production systems and promote animal welfare. Investigating naturally occurring disease and sub-optimal health has led to more emphasis on the relationship between animal health, economic productivity and sustainable food production. Food production veterinarians are playing an increasingly significant role in identifying farm practices that can be managed to protect ecosystem and public health and to promote sustainable food production and trade. It can be argued that aquaculture veterinarians and health managers lag somewhat behind their counterparts in other animal production systems simply because a principle task of salmon farming remains the control of infectious and parasitic diseases rather than managing sub-clinical disease to optimize productivity. Mortality rates due to infectious diseases remains higher for salmon farming than for other production systems such as poultry or cattle, therefore, significantly more time is spent on infectious disease prevention in salmon than on optimization of productivity through health management methods. It can be further argued that the herd health approach is a relatively recent addition to aquaculture management. Historical approaches to fish health focused almost exclusively at identifying and targeting pathogens. This led to the industry often chasing one disease problem at a time, looking for technological “fixes” like a new drug or vaccine rather than utilizing a more systematic approach to population health and disease prevention. However, population health management has now become widely adopted in the salmon farming industry as a health management paradigm.

Simply put, herd health is composed of 5 main factors:

- Surveillance to recognize disease challenges potentially confronting an animal population
- Response plans to signal when health management interventions are required
- Programs to enhance resistance to disease involving factors such as nutrition, water quality and vaccination
- Reduction of disease challenges through activities such as biosecurity, fallowing, hygiene, stress reduction and other measures
- Information management, planning and communication systems to coordinate, integrate and achieve herd health goals

The UK Farm Animal Council stated that are there five states or “freedoms” that must be provided to ensure animal welfare: (i) freedom from hunger and thirst; (ii) freedom from discomfort; (iii) freedom from pain, injury and disease; (iv) freedom to express normal behavior; (v) freedom from distress. There is increasing experience and evidence in agriculture that addressing welfare goals is an important component of meeting herd health objectives. There is little published research specifically on the relationship between welfare and health outcomes on salmon farms, but practical experiences and research in allied fields would suggest it is reasonable to assume that promoting the welfare of fish will also promote health outcomes. The concept of welfare does, however, create debate when it comes to aquaculture as some of the freedoms described above imply a capacity for conscious perceptions (or “feelings). Given debates about the capacity for fish to perceive pain, controversies about the capacity for fish to have feelings are hotly debated. Despite the debate, the evolution to a herd health approach in salmon aquaculture has brought with it an increased focus on enhancing and protecting fish welfare.

Hazard Analysis and Critical Control Point (HACCP) management has been adopted by much of the salmon farming industry to assess hazards and establish control systems that focus on prevention rather than reaction to undesired outcomes. HACCP certification is used by some companies as evidence of attention to specific production standards. Primarily used to meet the needs of trading partners for seafood safety, the HACCP approach reaches back onto the farm to prevent and control food safety and subsequently other disease risks. Often, good management practices or quality management practices arise from HACCP plans, thus fostering herd health approaches. For example, HACCP plans to avoid antibiotic residues in salmon at slaughter require attention to diagnostics and surveillance, record keeping and timing of treatments. HACCP requires multidisciplinary teams that can look at the entire food chain and find critical points where control measures can be applied. Expert opinion, experience, principles of food production and aquatic health, and applied research are often all used to establish where the critical control points lie. Unfortunately, there remains a deficiency of data regarding on-farm measures for controlling pathogenic microbes, thus complicating the establishment of evidence-based good aquaculture management practices at a farm level. The idea of applying a HACCP approach to the control of fish diseases not of food safety concern is gaining momentum and is consistent with herd health goals and practices. However, there is little published literature on the success of this approach for salmon farming.

As a core function of herd health is recognition and response to disease challenges, surveillance is critical. Surveillance begins at a farm-level. Most farms track patterns of morbidity and mortality and have some degree of in-house diagnostic capacity and veterinary support. Governments and academic organizations often provide additional diagnostic services.

Great strides have been made in technological advances in fish diagnostics. Lesser gains have been made in epidemiological aspects of surveillance such as how, when and how many fish to sample to support early warning and routine surveillance. Some recent research has show there are reasons to question historical approaches to tracking disease on farms. For example, data has shown that cases of IHN outbreaks often precede any change in mortality patterns so that earlier submission of fish for diagnostic testing could provide much sooner signs of an impending outbreak (St Hilaire *et al*, 2002). Previous work on chinook salmon farms revealed that focusing disease detection on surface swimming moribund fish created biased in disease detection towards finding chronic illness rather than acute diseases (Stephen and Ribble 1995).

The challenges of tracking diseases in wild fish however, greatly exceed those facing fish farmers. Testing protocols used in existing policies or practices typically require one to extrapolate the disease status of a sample of individuals culled from a group to the remaining members of that group. How the group was sampled will be one of the most important considerations when trying to decide the validity of extrapolation. For example, most disease surveys in Atlantic salmon in the 1990's were done on the more accessible, but demographically less important adult returning fish, rather than on early life stages or marine survival. Similarly, much of what has been derived on the epidemiology of bacterial kidney disease in the Great Lakes has been based on weir surveys rather than systematic samples across age classes and habitats. Evidence from wild species and cultured fishes demonstrate that fish will differentially distribute themselves with respect to their healthy cohort, which, in turn, affects their probability of being included in a sample. Pathogens may cluster in different sub-groups within populations and communities due to differed histories of exposure and susceptibility. Specific pathogens in Ontario hatcheries have been more commonly detected in certain species and age classes, indicating clustering within a location (Good *et al*, 2001). The capture method itself may affect what one can observe. For example, methods used by Bristow and Berland (1991) to survey wild salmon in Norway were not suitable for detecting external parasites simply because the capture methods and post-capture handling tended to cause ectoparasites to be dislodged from the fish. The prevailing reliance on periodic field surveys of wild fish alone as a method for describing population health can be misleading as it fails to account for other population and environmental factors that may be changing the number of cases of disease detected. Periodic fish disease surveys must be distinguished from surveillance. These surveys can provide "snapshots" of the types of etiologic agents in a population, but they are inadequate for generating the data needed to establish cause-effect relations or to establish population impacts. Because the distribution and abundance of disease is variable and under the influence of a wide variety of factors, a single, large-scale census tends not to be as effective as a sampling scheme that has a random component and samples only a portion of the population at frequent intervals (Farver *et al*, 1985). Unless investigators understand the capacity of their sampling method and the nature of the sampled population, it is not possible to confidently extrapolate the results of a survey to the general population. Resolving these deficits in our capacity to characterize the disease status of wild fish is fundamental to allowing us to understand the interaction of wild and farmed fish.

3.2.2 Identification of Critical Control Points

Identifying critical points in the production system when diseases can be prevented and/or when opportunities for wild fish to be exposed to farm diseases will require increased investment in epidemiological capacity. Much of what has been learned has come as a result of outbreak investigations or research into epidemic diseases. It is unfortunate that funding or motivation to conduct research on disease risk factors or control points has historically been motivated by urgent disease problems as opposed to a strategic plan for proactive research. One reason for this responsive rather than proactive approach is the dependency of regulations and HACCP plans on the need to identify a specific hazard (in this case, a disease). Compared to terrestrial agriculture, relatively little has been invested in "peacetime" research on the relationship between health outcomes, productivity and production or environmental risk factors. As many company's corporate philosophy are now embracing a quality management approach, the demand for more information on critical control points is increasing. Regulators and the public must remember, however, that critical control point selection does not rely exclusively on biological research. In addition to the criterion of effectiveness, a control point must be efficient. Economic considerations, therefore, play an important role in the selection of control points. This results in most attention being placed on controlling diseases or economic importance to fish farmers. One can argue that wild fish receive secondary benefits when any disease is reduced on salmon farms, but economic criteria may compete with ecologic criteria when selecting which diseases on which to focus HACCP-based health management plans. There is evidence that companies recognize the marketing value as well as the ethical responsibility to address diseases which may not be economically significant to them yet or concern to consumers for environmental reasons.

3.2.3 Codes of Conduct and On-farm Policies

Many large companies have extensive procedural manuals as well as management structures in place to support their herd health policies and practices. Some companies use third-party sources to evaluate and audit their procedures (like ISO) while in other cases, government audits ensure comprehensive health management principles and practices are applied (ex. BC government fish health management requirements). The capacity to implement these policies and procedures may be in-house and/or provided by allied service industries, such as private veterinarians. An advantage of salmon farming in the dissemination of standards of practice is that relatively few companies control the majority of production. This allows for the diffusion of herd health methods throughout many production sites once a company adopts and employs this approach. This differs from other animal production systems were ownership is more diversified and less centralized.

Private or public codes of practice govern a variety of salmon health issues, such as the Scottish Code of Practice to avoid or minimize the impacts of ISA. The British Columbia Salmon Farmers Association has codes of practices for a variety of health activities including bio-security, exposure reduction through waste management, husbandry activities and feeding. The BC provincial government has produced standards for the isolation and management of IHNV positive farms. Adherence to the codes is often a prerequisite for maintaining membership in industry associations. In some cases, they are also a condition for farm licensing. Most fish health codes of practice are focused on specific important diseases rather than development of comprehensive herd health plans. The latter seems more in the hands of individual companies.

Standards of practice are common for diagnosis of specific listed diseases for regulatory purposes. Many government agencies define the diagnostic criteria required for the classification of specific infectious diseases that serve as the basis for official reporting. Similar standard case definitions are rare for diseases not of regulatory concern. This has lead to some variability in the surveillance of certain diseases in the past and thus to debate and disagreements when public agencies have tried to develop surveillance or monitoring programs for fish diseases in general. For example, whether or not the isolation of an infectious agent was necessary and sufficient to diagnose a disease and/or to assess an environmental risk remains a contested issue for some diseases. The vast majority of diagnostic standards are hampered by the deficiency in research on the clinical performance of most diagnostic tests (false negative and false positive rates, predictive values). This lack of information has important implications for studies examining the transfer of pathogens from farm to wild fish and/or the detection of disease in wild fish.

Many government aquatic health programs focus largely on prevention of the importation and movement of specific infectious diseases rather than fostering specific health management practices; a position perhaps inadequate to support stated goals for sustainable aquaculture development. However, some more recent undertakings are fostering a population (herd) approach to aquatic health. Australia's AQUAPLAN requires aquaculture operations to prepare and plan for responses to specific diseases, and for monitoring and surveillance of specific diseases. Although largely focused on specific infectious diseases, the AQUAPLAN documents provide a foundation for herd health elements to be integrated into companies health management programs. The USDA Aquaculture Program is encouraging research into integrated aquatic health management. In Canada, the province of British Columbia requires all farms to have an improved fish health management plan which serves as foundation for herd health programs.

While the principles of herd health are well established for terrestrial animals and the benefits documented by research, the evidentiary basis for herd health standards and methods are scarcer for salmon farming. Comparatively little research has been published to determine which specific management practices can best contribute to herd health goals. The working group charged with developing provincial standards for population health management in BC salmon farms found it very hard to find published data from which to recommend best practices. Personal experience and expert consultation were required to formulate the practices. This resulted in more goal-based recommendations than specific standards for herd health. Companies were required to argue that their individual approaches were sufficient to meet those goals. While this may not help in developing a standard set of practices, it is perhaps more reflective of the need to recognize that standardization of health management may be elusive as local conditions and goals will differ between farms thus necessitate different approaches to disease prevention and health promotion. However, the industry would be well served by investment in research in population health management methods to assist it in developing evidence-based herd health and to provide governments with a more solid basis for auditing and assessing health management plans.

Chapter 4: Managing Disease Risk

4. Can we reduce disease impacts on farmed and wild fish

Diseases, both in nature and in farming, are virtually unavoidable. In aquaculture, the impacts of disease are often ultimately measured in terms of economic or animal welfare effects. The history of salmon farming has shown the potential for remarkable impacts of disease on the industry profitability. In nature, the effects of disease may ultimately be measured in terms of population viability, fecundity, survivorship, or abundance. The effects of disease in natural systems on such measures remain unclear in many instances and vary from species to species and place to place. While the effects of disease on marine fish is poorly understood, there is analogy from other species that suggest that diseases from domestic species can have significant impacts on free ranging animals (Lafferty and Gerber, 2002). There is, therefore, incentive to identify effective and necessary practices that are capable of preventing or reducing the negative effects of disease on both wild and farmed fish.

In this chapter, we present a general review of critical features of measures to detect, prevent, treat and control disease. Our goal is to opportunities and gaps in practices that may inform the selection of risk management standards. At the end of this chapter, a case study is provided that describes details of programs and practices in Chile.

4.1 On farmed fish

Within any salmon population, health exists as a wide spectrum ranging from completely healthy to terminally sick individuals. Generally, optimal health status promotes greater resistance to infectious disease and better growth under farm conditions. At the other end of the spectrum, fish of poor health, which are often compromised by inadequate growth, nutrition or environmental quality, are more likely to contract infectious agent and express clinical disease symptoms following infection. These individuals usually do not recover well from the stress of routine husbandry events and as a result are more likely to die of their after events such as handling. The goal of fish health management on farms is to shift the proportion of fish on the farm towards a high percentage of highly healthy animals held under optimal rearing conditions.

Host and environmental variables play keys roles in modifying the impact a disease agent on an individual or population. For example, smolt transfer requires a major physiologic transition in which the fish must adapt to an entirely new osmotic environment while potentially being exposed to new disease agents. If this major event in the production cycle were to occur in an area where, for example, IPN virus was present, clinical IPN with sudden and drastic increases in mortality rates would most likely be observed 2-3 months after smolt transfer (Roberts & Pearson, 2005). If those same fish carriers of IPN virus, the stresses caused by the marine adaptation could cause enough stress to convert their subclinical infections to clinical disease. The combination of host and environmental stressors affect the probability of clinical disease occurring in an individual, a cage population, a site population, or an entire region. Modifying husbandry and host factors contributes to the disease prevention strategies employed by farmers to first reduce the probability of exposure to important disease agent and, second to reduce the probability that clinical disease will occur if exposure is unavoidable. In our IPN example, efforts to reduce the probability of exposure (by avoiding smolt transfers to areas of historical IPN problems), to avoid transfer of IPN carriers, to minimize stress at smolt transfer and to increase the host resistance (through vaccination) are among the potential IPN disease control measures available for salmon farmers. Modifying similar environmental stressors affecting wild fish is typically beyond the scope of fish disease programs as they may involve larger scale environmental perturbations such as habitat loss, pollution, climate change, changes in predator-prey relations or similar factors. Disease prevention and control in truly wild populations has few options.

Approaches to disease prevention that serve to reduce fish susceptibility and environmental stressors are commonplace in aquaculture. They are not, however, 100% effective. Salmon farms are still left to control diseases that exist on farms. This chapter examines methods needed for the detection, early response and treatment of disease in farmed and wild fish.

4.1.1 Monitoring / surveillance (presence, levels, and patterns of disease in farmed fish)

The first component of reducing the impact of infectious disease on salmon farms and the interaction between farms and wild fish is to be able to detect new introductions of disease agents as soon as possible, preferably prior to any transmission within the region. The next step is to quickly respond to reduce or prevent transmission and lastly to minimize the negative influence of the disease on both wild and cultured populations if it is endemic. Surveillance (which includes plans and methods to detect, assess and respond to disease issues) is, therefore, the foundation of actions to prevent and reduce disease impacts and should be part of any standards intended to control the impacts of disease.

Surveillance plays four key roles in salmon farming: (1) It allows for the detection of new diseases; (2) it tracks of the prevalence, distribution and rates of endemic diseases; (3) it provides information that can be used to trigger responses to disease events; and (4) it allows one to measure and assess the effects of disease control interventions. Surveillance begins at a farm level. Daily to weekly determination of crude mortality rates provides information on the population level of clinical disease since many diseases often cause mortality in salmon. The proportion of fish that have visible change in their health status, considered obviously ill or 'clinical' in disease expression, is another useful indicator for disease occurrence that is routinely monitored in farms. Changing behavior of the fish, particularly decreased appetite, is an early sign of the group health status. Fish farms have the ability to closely observe fish all of these outcomes and behaviors. The experience of daily feeding and working with their livestock leads to an acute awareness of small changes in these surveillance measurements. Wild fish likely experience similar changes but they can rarely be witnessed by humans due to the lack of opportunities or methods to observe such changes.

Diagnostic testing of mortalities is usually intensive in fish samples from farm mortalities as it is in the best interests of farms to have early diagnosis of new diseases if control options are to be effective. Classifying crude mortality into cause-specific mortality is feasible and assists in further refining surveillance and mitigation strategies (Aunsmo *et al., 2008)*. Monitoring mortalities for disease signs and utilizing these carcasses for diagnostic testing have been very useful for early determination of the introduction of a new pathogen to a farm or a region. The emergence of diseases new to areas, sometimes even new to science, is relatively common in aquaculture due to the lack of history of direct observation of fish populations (Hutson et al., 2007). Fish disease agents recently discovered, such as Infectious Salmon Anaemia (ISA) virus discovered in the early 1990's (Dannevig *et al.*, 1995), have the benefits of molecular diagnostic tools developed for other applications but used to investigate fish pathogens. Kibenge *et al*

(2000) discovered a togavirus when investigating mortality patterns in eastern Canada, which eventually were proven to be ISA related, but many fish had apparently benign coincidental infections with togavirus.

There can be, however, great difficulty in determining if a newly detected pathogen is truly new to a region. Many factors contribute to this dilemma, including the fact that diagnostic tests can have false positives. This is happens when the specificity of the test (proportion of true negative individuals that test positive) is low. Erroneous test results can confound the interpretation of the test that find new pathogens, especially if the host population is in equilibrium with a related non-pathogenic organism that cross-reacts with the test for the disease of concern. For example, diagnostic tests considered positive for ISAV have recently been identified as reactions to non-pathogenic genotypes of the ISA virus, while the test was positive for the virus it was not positive for the genotype of the virus that causes clinical disease (Nylund *et al*., 2007). Alternatively, some diseases may have been present for many years or decades but the opportunity to identify their presence did not exist until salmon farming generated the incentive to investigate. For example, molecular and serological evidence suggests that ISAV has existed in Eastern Canada and the Northeastern USA prior to the outbreaks in the 1990’s (Krossøy *et al*., 2001; Cipriano, 2008). Diagnostic efforts employed prior to the ‘emergence’ of ISA in Eastern Canada could thus be considered false negative. Possible components of this failure to detect ISA prior to its emergence on farms include the lack of observation and testing of wild salmonids, the lack of a sufficiently sensitive test, and the lack of incentive to investigate the presence in local populations. Farming changed the last two, but not the first. Identifying and sampling mortalities in the same manner from wild populations is rarely possible unless there are massive numbers of dead fish in areas observable by people, such as was seen with the pilchard herpesvirus mortalities in Australia when at least 10% of the population died over a relatively short period (Whittington *et al*., 1997).

Surveillance serves to not only detect new problems, but also to track endemic diseases. In this way, producers can hopefully be forewarned of impending diseases outbreaks and respond fasters to exert control and reduce the extent of the outbreak. Farmers help use these data to establish seasonal high risk periods so they can adjust management and resource allocation for disease control. Some governments, such as the province of British Columbia, Canada, add onto company level surveillance by auditing visits to farms to independently measure disease trends. Such data has helped direct disease control policies and programs.

Surveillance remains imperfect and thus can miss changing disease patterns. This is sometimes due to the expense and inefficiency in investigating all mortalities that may occur or simply due to the failure to examine all poor-doing animals in production. Wild fish have predators to remove weaker animals from the population (Mesa et al., 1998) while farms do not have this automatic removal mechanism. As a result, many of the poor-doing individuals will remain in the population much longer than in the wild, providing observations of an apparently higher prevalence of weaker fish (compared to wild) and allowing their increased susceptibility to infectious disease to manifest itself in new infections. This ability to access sick fish more easily in farms than in the wild has been cited as a reason for finding more disease is farms than in the wild (Stephen and Iwama, 1997). In other instances, low numbers of mortalities go uninvestigated and will remain unclassified as to specific cause because they are generally not thought useful in predicting infectious disease outbreaks and therefore do not justify the expense of pursuing diagnosis. This is not always the case however. For example, in 82% of IHN cases in outbreaks in British Columbia in 2001-2003, the virus could be found by active surveillance in advance of spikes in mortality rates (Saksida, 2003). It is unrealistic and inefficient to expect all cases of unexplained or low-level mortality will be investigated by experienced diagnosticians. These intense investigations are usually reserved for cases suspected to lead to new diagnoses or economically important diseases.

Non specific causes of mortality are relatively common in aquaculture, a fact reflected in surveillance reports. Such findings reveal the need for research. Although the diagnostic investigations follow similar routines and rigor as they do in disease investigations of terrestrial livestock, there is less history and critical mass of scientific literature on which to base conclusions about etiologies. Many farming regions have record systems that encourage general classification of mortalities and non-specific reasons for mortality. Such mortality classification records are extremely useful in detecting changes in patterns of mortalities and, thus, in identifying emerging health concerns (Aunsmo *et al.*, 2008). This is useful to identify trends but it is also subject to misinterpretation if the gross lesion classification is not further verified in a subset of cases. Almost all salmon growing areas in the world have gradually reduced the proportion of unexplained mortalities through improvements in surveillance systems.

Fish health professionals visit fish farm sites frequently in virtually every salmon producing country for routine health management on-farm and early detection of diseases. In Norway visits occur at least every 8 weeks and in Canada every 4-8 weeks. In Chile, official programs dictate visits every 4-8 weeks but most companies have corporate veterinarians or contracts with private veterinary practices to visit as often as every second week. Most governments provide some oversight by periodically visiting to take samples or audit the company sampling procedures. Some jurisdictions (e.g. Norway and Eastern Canada) have regulations that require a mandatory frequency (usually 6 times per year) of routine visits, followed by a system of reporting and investigating unexplained mortalities. A Program of Passive Epidemiological Surveillance in Chile requires routine reports from private diagnostic laboratories monthly.

Decisions regarding appropriate methods for surveillance are dictated in part by the expected prevalence of the pathogen in the population. If the disease agent is endemic in the population (i.e. existing at some level), it may be necessary to sample apparently healthy fish at points in the production cycle (when random selection is possible). Should the prevalence of disease increase, containment actions may need to be implemented. Changes in distribution of disease within different sub-populations, such as younger fish, may reflect changes in the probability of transmission to other farmed sub-populations or wild fish. Subsequent actions might include changes in husbandry or treatment strategies aimed at reducing the infectious pressure or improving the resistance of the population.

If the disease agent is exotic to an area, particularly if the potential consequences of its introduction are severe, early detection is critical. In this instance, detection of the first case may warrant more immediate and drastic action to contain the disease. Successful containment of the disease agent is beneficial to the entire industry and to surrounding wild fish populations, sometimes at the expense of the owners of the first case. If the expense of control (e.g. depopulation measures) of early cases is completely the responsibility of affected sites / companies but the benefit is to surrounding sites or wild fish, there will be challenges in maintaining the cooperation of affected sites. This is even more of a challenge if the early cases are false positives.

Adequately trained and available fish health professionals are critical for effective surveillance. The fish health expertise to diagnose and manage disease is very developed in all the major salmon producing countries and there is excellent information exchange through peer-reviewed literature and scientific conferences. Fish health technicians visiting the production site play a key role in routine surveillance. They are typically trained in identifying lesions in a repeatable manner between individuals. It is important that these technicians also be trained in identifying the limits of their capabilities so that they can consult or transfer the cases to more qualified diagnosticians. Field technicians are the first line of defense in any surveillance program designed for early detection of new and emerging pathogens and generally have been incorporated into the surveillance schemes of most salmon producing areas.

Countries such as Canada have a strong veterinary profession integrated into the salmon farming industries, but there is difficulty in attracting and retaining veterinarians with post-graduate training in aquaculture. Norway has a very large veterinary and professional fish health biologist infrastructure and also a strong fish health research support, whereas Scotland has only a small number of veterinarians working in aquaculture but a large number of fish health biologists concentrated in diagnostic or research laboratories. Chile has many veterinarians working in the industry but only a portion of these are working in a diagnostic capacity. Chile also has many private diagnostic laboratories supporting the industry. Laboratory methods for disease surveillance are usually well developed for the salmon farming industry as it is sufficiently large to generate the economic need for diagnostic support. Surveillance and control programs for public interest demand substantial public investment which must be justifiable (Moran & Fofana, 2007).

Diagnostic skills for salmon diseases has improved greatly over the past 10 to 20 years, driven in large part by the economic importance of disease limitations on salmon production and the increased value of salmon aquaculture. Improvements have come from increased effort and resources dedicated to training, research, and service. Many programs recognize the need to have certification processes to verify that the diagnostic capabilities of a region are reliable for international trade purposes. Although many improvements have been accomplished, there remain challenges in the diagnosis and interpretation of surveillance and diagnostic findings. One of the main challenges has been the distinction of infection versus disease versus impacts. Surveillance and research has found a variety of pathogens in fish. New molecular diagnostic methods increase the capacity to find pathogens. Apparently new microbes have commonly been found in surveillance sampling, especially when only sick fish have been examined. It has been tempting to conclude that newly detected microbes are the cause of the illness. However, weakened fish are generally less resistant to opportunistic bacteria or viruses and this can lead to proliferation of these organisms in dying or dead fish completely unrelated to the cause of the illness. In other cases, there is a microbe-host equilibrium in healthy fish which is discovered when subjecting fish to new diagnostic procedures. Laboratory diagnosis must be complemented by on-site investigations to ensure that early detection and targeted sampling results are properly interpreted. Access to the full spectrum of fish disease and veterinary services are, thus, an essential part of surveillance programs.

It is equally important to determine if negatives test results truly are negative, known as diagnostic specificity. The diagnostic sensitivity and specificity values for most aquatic diseases have not been determined using natural infections from field samples. However, recent advances in statistical modeling that can accommodate the complex analysis of diagnostic test performance in the absence of gold standards (i.e. known positive and negative) have opened this field for all species, including humans, terrestrial and aquatic animals. Knowledge of diagnostic sensitivity and specificity, the within and between laboratory repeatability, and the interpretation of presence / absence or prevalence data from surveillance programs are all important considerations and will be valued differently by farmers, clinicians and policy makers (Ransohoff, 2002). Evaluations of the performance of diagnostic tests should incorporate infections that mimic the conditions expected in their use. However, this means that the evaluations use diagnostic material from individuals with unknown infection status (Enøe et al., 2000). This aspect of surveillance is very important since conclusions are made about the presence of infection in the proportion of animals tested and misclassification error must be incorporated into the interpretation (for ISA examples, see Nérette *et al.*, 2005a; Nérette *et al.*, 2005b; or IHN example, see McClure *et al.*, 2008). Unfortunately, this area has been subject to relatively little research. Assessments of surveillance programs that include assessment of diagnostic test performance are usually large in scope and relatively expensive. They usually require large samples sizes and potentially large scale, multi-centre trials to evaluate their robustness and potential for 'laboratory effect' (Cunningham, 2002). Although difficult to accomplish, the information is essential to improving policy decisions regarding control actions.

Diagnostic criteria for disease definitions are often not internationally standardized and sometimes remain confusing within regions as well. Diagnostic classification of salmon diseases, as in many species, requires consistent case definitions. The clinical presentation of the 'same' infection in different locations can vary widely (e.g. Hemorrhagic Kidney Syndrome was the early diagnosis for ISA outbreaks in Eastern Canada, Byrne et al., 1998). However, the source of samples and the disease investigation methods as well as the host genetic differences, environmental interactions, and the farm husbandry factors will all affect the disease manifestation to some degree. Many of the details of case definitions and the manner in which they are reported differ between regions, sometimes within regions of the same country. For example, an area such as New Brunswick, Canada, may define a case as two positive tests on two separate fish derived from an ongoing formal sampling of moribund fish (every 6-8 weeks) with no connection to increased mortality levels. Another area such as Norway may define a case as one in which increased mortality rate resulted in farm fish health managers seeking a diagnosis and had at least two fish test positive by viral culture. In the former situation, mandatory testing detected many more cases unrelated to mortality rates (refined after 2005 to reflect pathogenic genotypes in the 'positive' category) and in the latter, lack of mandatory testing results in under-reporting of cases (i.e. cases by the stricter definition in the first area). Comparisons across jurisdictions are essentially invalidated when such differences in case definitions exist. Consistency in diagnoses has improved by through utilization of OIE diagnostic procedures and sharing of information through OIE Reference Laboratories.

The standardization of case definitions and requirement for disease reporting may inhibit appropriate surveillance of the disease if farmers would rather avoid the diagnosis and subsequent regulatory action as opposed to avoiding the disease. Promoting best practice standards locally may not always benefit from dictated international case definitions. Comparing disease frequency data across jurisdictions either requires international standardization or detailed knowledge that would enable a conversion of disease information to a comparable format. Knowledge of number of animals at risk, sampling frequency and methods, diagnostic procedures, diagnostic test performance, and other sources of error are needed to identify the confidence and comparability of surveillance information from across jurisdictions.

The OIE Aquatic Animal Health Code provides a general overview of the design of disease surveillance programs. However, application of specific actions within the surveillance programs differ between jurisdictions due to the dynamic interaction between health service capacity, the industry composition (i.e. site ownership) within the regions, and government regulatory programs. Compared to other aquaculture species, salmon disease surveillance is normally more intensive, reflecting the relative economic importance of salmon. In British Columbia, for example, there is surveillance at a company, industry and government level for salmon farming, but no equivalent for terrestrial farming except for a few specific diseases of concern. This multi-layer approach to surveillance has allowed for a more complete view of patterns of disease. For example, in 2007, these combined findings revealed how non-infectious disease or injury were the most common causes of Atlantic salmon deaths in the province (http://www.al.gov.bc.ca/ahc/fish_health/fish_health2007.pdf) . These reports are made available to decisions makers as well as the public and help refine disease management programs. Critics of the report cite lack of site specific data as a deficit of the program.

The ability to declare freedom from specific pathogens in a region is crucial for international trade and for general area disease management. Although knowledge of pathogen absence is important for policy decisions, it is rarely useful to assist in day-to-day health management decisions. Occasionally, susceptible sentinel fish will be employed to determine if an area still contains a pathogen following a fallow period after depopulation (St-Hilaire *et al*., 2001). The first occurrence of an infection that leads to transmission and clinical manifestations is important for those decisions, hence a surveillance system designed to detect the earliest case is very important to area management of disease. For example, IHN was not detected prior to the movement of farmed fish between sites and contributed to further transmission (St-Hilaire *et al*., 2002). Although a laudable goal, it should be recognized that the *first* occurrence can rarely be identified through any surveillance program unless 100% of infections lead to severe and pathognomonic lesions, a situation which rarely, if ever, occurs. Complicating this situation, infection in an individual fish is not guaranteed to lead to clinical disease or to further transmission within the population without other factors contributing to its spread.

The entire surveillance process, from population sampling to interpretation of results, has certain limitations that must be recognized. Sampling biases or fish availability will affect the probability (usually in an unknown way) that an infected individual will be included in the sample. Compared to wild populations which are much more difficult to observe, accessing mortalities or moribund fish is possible at fish farms due to the ability to closely observe the population. Sick fish are useful in detection of emerging diseases if the incubation period is short and illness or mortality is a common outcome of the infection. For this reason, salmon farms and their veterinarians utilize mortality collections as the primary opportunity to assess the disease and infection status of groups (e.g. cages) and sites. The effectiveness of this approach is reduced when the disease of interest is less likely to cause the fish to end in the moribund or mortality category (e.g. ISAV infections in rainbow trout, Nylund et al., 1997, or wild salmonid reservoirs for non-pathogenic genotypes of ISAV, Plarre et al., 2005), or has a long latency period prior to reaching levels that are routinely detectable (e.g. BKD infections in rainbow trout, Hirvelä-Koski et al., 2006). For these kinds of infections, some form of representative sampling from the entire population must occur. Calculating prevalence from such sampling is problematic as true random sampling is rarely possible at fish farms and the low prevalence and / or the low pathogen burdens of subclinical infections (as suggested for ISAV infections by Jørgensen et al., 2008) may affect the performance of diagnostic tests.

Surveillance can, in principle, provide critical data for understanding the ecology and epidemiology of salmon diseases. Calculations of the transmissibility of a pathogen within a cage of fish (e.g. R_0 values which reflect the number of new infections caused by an infected individual) have been lacking in aquaculture due to the inherent difficulty in understanding the relationship between infection and the outcomes and the high cost of doing large scale sampling in productions cages for research purposes. There is evidence to suggest that low mortality does not mean low prevalence of infection for some disease like furunculosis (Ogut *et al.*, 2005) and likely many viral diseases (e.g. IPN, VHS depending on the host species) as well. Work is continuing in the modeling of infections based on mortality records available from fish farms (e.g. McClure *et al.*, 2005) but the research activity in this area needs a much greater emphasis to benefit understanding of disease dynamics in both aquaculture and wild fish. Tracking routine and required surveillance data may help to overcome these obstacles to understanding.

Every fish health surveillance and control program has pre-defined thresholds of increasing mortality rate (i.e. deaths per at-risk population per day) to initiate further diagnostic investigation. In most areas, this threshold is based on previous experience about the expected 'background' level of mortality but this is surprisingly consistent across jurisdictions. A threshold of 0.05 % mortality per day is frequently used in salmon marine sites to indicate when mortalities have converted from background to a situation requiring further explanation. This level is adjusted up or down depending on local conditions and perceived risk of disease outbreaks. Although the threshold of mortality rates that incites further investigation is relatively standard, it is often an informal policy. Formalizing this threshold into regulation has been done in some jurisdictions but enforcing its practice requires that crude and cause-specific mortality rates be reported to regulators to identify events that require explanation. This requires a centralized database that, in turn, requires investment in maintaining a usable data structure and verification of investigation results. Too often strict regulations exist for reporting confirmed infectious disease diagnosis but are lacking in legislative language to enforce rapid and thorough diagnostic investigation of mortality events. It is, however, almost always in the best interests of the farm to identify a reason for losses in order to make decisions concerning remediation. The confidence of the other operators, public policy makers, and the general public is undermined by not having a formalized and independent central record system of mortalities, their cause, and an assessment of the risk of spread to other farms or wild fish (Hammell & Dohoo, 2001).

Disease control measures are often enacted when specific thresholds are exceeded in surveillance findings. Usually, responses are designed to achieve goals set for the farm. It has been difficult to identify when the economic and ecosystem consequences of inaction are outweighed by action that will cost individual farmers, such as depopulation in case of viral disease outbreaks. Risk of further transmission must be balanced against probabilities of disease occurring regardless of the control action. These decisions are frequently made in the absence of solid evidence. The situation in which the disease control measure costs salmon farmers more than the actual disease losses is a very real possibility. However, the outcome may be irreversible once a decision is made to allow a transmissible disease to continue its course.

4.1.2 Prevention, treatment and control options

There are many options for managing disease on salmon farms through prevention strategies, treatment, or change in host resistance (i.e. vaccination or long term genetic selection).Treatment of most infectious diseases is considered secondary to disease prevention which, in turn, is considered secondary to prevention of infection. Only the most important aspects of disease prevention and management will be considered in this report. The following section will address the principles of salmon farms disease management from the perspective of prevention of infection, prevention and reduction of clinical disease expression, and finally, treatment with drugs. Although disease control in wild salmon is considered in a separate section, most of the control options applied to farmed fish will benefit wild fish by reducing the potential for transmission *to* wild fish and, therefore, will be briefly mentioned in this section.

It is common to try to attribute early cases of exotic disease to poor health management practices at the site. Occasionally, management practices have been the source of new introductions. Importation risk assessments are essential to identify and control the greatest risk activities (see for example Peeler and Thrush, 2004, for qualitative risk analysis of *Gyrodactylus salaries* introduction into the UK). Despite frequent evidence to support salmon diseases being spread by horizontal transmission between farms (e.g. ISAV in Norway, Lynstad et al., 2008), their first emergence rarely is attributable to introduction by farming (e.g. IHN outbreaks in Western Canada, Saksida, 2006). Even when farms have not introduced the pathogen, farm practices have frequently been implicated in enabling the transmission of the disease agent between farms and potentially to the wild (e.g. ISA transmission through farm management factors, Hammell & Dohoo, 2005b, and through harvesting practices, Munro *et al.*, 2003; IHN transmission factors: St-Hilaire *et al.*, 2002, and many other examples).

It is rare that a single farm practice can be attributed to the introduction and spread of a new pathogen. It is more common that a combination of factors contribute to the increased probability of introduction and transmission of infection and the development of clinical disease (e.g. ISA risk factors outlined in McClure *et al*., 2005, or Gustafson *et al*., 2007b). For these reasons, comprehensive biosecurity measures which form barriers to the introduction and spread of diseases agents are critical. Establishing barriers to transmission between tanks in a hatchery or cages at a marine site is an important component of managing disease in farmed fish. Clinical disease outbreaks can generate mortality in one cage while a neighboring cage, with fish of similar background and similar rearing conditions, exhibit no signs (e.g. ISA outbreaks in eastern North America: Hammell & Dohoo, 2005a; Gustafson *et al.*, 2007b). Stopping their spread greatly reduces the disease impacts.

Arguably, the most important disease prevention strategy realized by forming barriers to transmission is the implementation of single year class sites. This practice is adopted from swine and poultry production where all-in-all-out stocking has been common practice for decades. The biological principle is simple: avoid exposure of younger to older animals. Older animals are more likely to carry infectious agents but less likely to show illness from those agents while younger animals are less likely to already have the infection and more likely to experience illness once exposed. Any release of pathogens from infected, but apparently healthy, older animals have the potential to infect younger animals nearby. Younger animals are less likely to have developed the disease resistance capacity of older animals and have more time to be affected by a subclinical infection once it is contracted. Although less common, older animals may not have been previously exposed to a certain pathogen that is more common in freshwater and so can experience the opposite direction of exposure whereby infected but apparently healthy smolts subject older generations to a new infection to which they are susceptible. This occurrence happens less often but can be even more costly since the value of subsequent losses of older animals is always greater than the loss of younger fish.

At some point in their history, most jurisdictions allowed multiple generations on the same site but separated them in different pens. The reasons were motivated by the economics of maintaining a single site that generates fish for market year round. There are many advantages to minimizing the personnel and resources required to produce salmon throughout the year. However, these are all surpassed by the economic disadvantage of disease exposure from older to younger animals. In the absence of major infectious diseases, which cannot be said of virtually any salmon growing area of the world except perhaps New Zealand, multiple year class sites require less financial investment compared to single year class sites when production levels are relatively small. However, when *any* transmissible disease is present, the use of multiple year class sites is a practice bound for failure.

The great advantage of single year class sites is that they reduce risk to many infectious diseases simultaneously provided the disease is transmissible through close contact of individuals. The disadvantage is that the production cycle of salmon is usually more than one and sometimes more than two years long (when time between generations is factored in), creating the need to have 3 distinct sites to meet the objective of continuous production. This has caused a policy conflict between providing new site leases to operators to develop a salmon production site or providing existing operators with opportunity to expand. In addition, it takes more investment capital and planning to operate three sites as opposed to one. A final factor to consider in the policy of single year class sites is that stocking numbers are virtually certain to increase since each site has a certain capacity to raise fish and it is rare to find an operator moving from a multiple year class site to single year class sites who does not wish to maximize the return on investment for operating the site. The result is that there is a greater total number of fish raised by that operator.

Partial violation of this single year class policy occurred in eastern Canada where the policy was generally, but not universally, implemented to reduce the risk of ISA transmission from older to younger fish. When insufficient sites were available, a small number of farms that had been free of ISA in their current production cycle requested permission to ‘hold-over’ a small number of market-sized fish to harvest over the summer months but continue with the usual smolt transfer to the site in late spring. Although pens were separated by the maximum distance possible within the site, this resulted in the site becoming a multiple year class site for 2-4 months and then reverting to a single year class site once the market fish were harvested in late summer. The practice was eventually abandoned because too many smolt pens were being detected as ISA positive despite the older fish never exhibiting clinical disease. The experience reinforces the fact that any period of time with multiple year classes present at the site essentially negates the benefits of the year class separation.

Taking this principle one step further, multiple year class *areas* represent greater risk for exposure of younger animals by older since all sites in the area do not contain the same age of fish (see, for example, McClure et al., 2005). However, there is an economic competition between the certainty of increased cost and logistical complication inherent in arranging single year class areas versus the benefit of reducing the risk of disease transmission between sites within the same area. The dictating factors in creating single year class areas seem to be 1) geographical / water current separation potential, 2) history of very high disease transmission risk between sites, and 3) willingness of industry and policy makers to commit to the strategy. The biological factors that will inhibit the full benefit of making entire areas the same year class include, but are not limited to: 1) potential for direct water exchange over a time period equivalent to the longevity of pathogen survival outside of the host, 2) sharing farm equipment or personnel between areas, and 3) wild carrier fish moving between areas.

Wild carrier fish can act as disease vectors between farms or can transmit their own endemic diseases, acting essentially like a different year class exposing, or being exposed to, farm fish of a different generation and disease exposure history. Thus, wild fish may collapse the barrier between farm generations. The magnitude of that collapse depends on the size and age of the wild population interacting with the farmed fish and the pathogen(s) involved. Assuming that older fish are carrying a specific disease, magnification of disease risk introduced by farms is a mix of older wild salmon exposing younger farm salmon in certain seasons, thus spreading disease *to* farms (e.g. proposed transfer of IHNV in Saksida, 2006, or proposed transfer of ISAV in Nylund *et al.*, 2003), and in other seasons older farmed salmon exposing younger wild salmon, thus spreading disease *to* wild fish (e.g. proposed potential for VHSV in Skall *et al.*, 2004).

Collaborative area management in which all sites act independently but use non-conflicting health management strategies appears to be practiced to some degree in some areas, including eastern and western North America, Scotland, and Ireland, but only sporadically in Norway and Chile. Additional to the influence of ownership history and business practices, this likely developed due to geography and the ability to separate sites within different inlets and channels which at least partially justifies it as its own ‘area’. Area management for disease needs to consider the strengths and weaknesses of having farms in a specific area act similarly with respect to disease management. Farms in the shared are still need to protect themselves from risks from neighboring farms even if those farms are in the same management area. For example, salmon alpha virus appears to be much more capable of transmitting within areas perhaps owing to sharing of equipment between sites within the area.

An important extension of the practice of avoiding exposure between fish generations is to completely remove the source of infection (i.e. the host) for a period sufficient that the risk of new disease cases returns to its background state. This practice is called fallowing and also has implications for environmental remediation (covered by other working groups). The practice of fallowing was initiated in the early 1990's primarily driven by the benefits for sea lice control in Scotland (Bron *et al.*, 1993) which is discussed in section 4.1.2 of the sea lice report and for furunculosis and ISA control in Norway. Meaningless when year classes are mixed at the same site, fallowing became more and more common as year classes were separated.

Although the principle of fallowing is easily justifiable, the difficulty arises when trying to define the minimum fallow period. Most jurisdictions have established minimal fallow periods as 4 to 8 weeks, or longer, that are adjusted based on disease history or risk for the site. For example, Norway has a 2 month fallow between generations unless there was a notifiable disease, such as ISA, present in the previous generation; then it is adjusted to 6 months. Chile has a 4 week minimum fallow policy that is lengthened when ISA is detected. Eastern Canada implemented a 8 week fallow between generations in an entire area, known as Bay Management Areas (BMAs) so that the actual fallow period would be as long as 6-10 months for individual sites that harvested early in the cycle but shorter for the last site to harvest (this is also adjustable longer if there is high risk of ISA in the area). There is debate, especially from producers who wish to stock sooner, about what is a justifiable minimal fallow period and when does the disease risk return to background level resulting in no added gain but more added cost. Much of the decisions regarding fallow duration have been dictated by breaking the sea lice cycle (discussed in sea lice report). However, the optimal fallow period is really based on the one required for the disease with the longest sustainability of infection risk when farmed salmon are absent. Many variables will affect this, including the presence of wild species able to harbor the infection, survival of the pathogen in the environment, and the disinfection protocols applied to farm equipment. Ultimately, long term epidemiology studies should add to the field evidence of what works for a fallow period, such as the example given for IHN fallowing by St-Hilaire *et al.* (2002).

The benefit of fallowing at a site is undermined by neighboring sites fallowing at different times, resulting in a scenario of 'hold-over' older fish in the same area as younger fish are introduced, similar to the site 'hold-over' situation described earlier for year class separation. Fallowing is also more effective when employed simultaneously in regions. However, there is some merit to the argument against increasing the complexity of regional synchronization of multiple company activities because it is very difficult to define an 'area'. In general, the area would be one in which one site affects any site outside of the area at the same level as the background risk (i.e. as if the site did not exist). This requires detailed knowledge of currents and water exchange as well as local wild fish migration patterns. Jarp and Karlsen (1997) and Vågsholm et al. (1994) both identified 5 km as a 'safe' distance in Norwegian ISA risk studies but this is an oversimplification since the data they had available was amenable to distinguishing between areas and the actual distance was not dictated by any biological reasoning. McClure et al. (2005) showed that decreasing distances between sites, even at very small distances, had increasing risk for ISA outbreaks. The most important aspect of synchronized area management is that 'more is better,' but at some point the cost will outweigh the benefit of optimal disease control at some distance that is dictated by local conditions.

When viral diseases occur in a population, they can be devastatingly rapid and severe. Because there is no treatment available to stop viral entry or replication in the host, there are few options for control. Once confirmed in a population, the primary consideration is to optimize survival of the entire group, where group may reflect the site, the area, or the entire industry. Optimal survival is accomplished by reducing exposure of naïve to infected individuals by culling, or depopulating infected populations before they have sufficient contact time or numbers of infected fish transmitting infection to new individuals. This is a race that is easily lost if there are any delays in detecting new infections or removal of infected groups. The stakes are high since the vast majority of the group (e.g. pen) will be virus free at the time of depopulation meaning that the still healthy fish going to early slaughter had a chance that they would have remained healthy if grown longer. However, there is a greater chance that the virus will cause more deaths if left to spread. Depopulation policy can be difficult to sustain because doubt is cast on diagnostic test capabilities when trying to detect infection prior to the onset of mortalities (Nérette *et al*., 2008) and the economic cost of depopulation falls to the producer while the economic benefit is shared by the neighboring farms and region. Nevertheless, early depopulation remains one of the few options for reducing the overall impact of serious viral disease outbreaks.

Site location is an important consideration for disease management. Much of the argument for appropriate site location can be incorporated as an extension of the argument for year class separation and fallowing and depends on environmental influences of water movement between sites and the nature of wild fish distribution. The goal of optimal site location for disease risk purposes is to maximize water quality to avoid negative effects on the disease susceptibility of the fish, and to enhance the control measures of year class separation and fallowing. Additional consideration is given in some jurisdictions to locating sites at distance to vulnerable wild fish populations; where vulnerability may be defined by the aggregation of wild fish of certain age class, susceptibility, or population status. These can considerations wild salmon and their spawning corridors and nursery areas in some jurisdictions.

Biosecurity is broadly defined as steps to avoid a biological harm and it is critical to disease prevention and control. It involves many different aspects that are beyond the scope of this report. The following is a short description of some important biosecurity issues that should be considered when developing best management practice standards.

1) Equipment sharing has been identified in several risk factor studies as important to the transmission of pathogens, particularly viral and bacterial agents (e.g. Hammell & Dohoo, 2005b, identified sharing of personnel or equipment as a likely risk factor for ISA outbreaks; and Murray *et al.*, 2002, associated well boats with ISA outbreaks). Well boats may be particularly dangerous as they can be used to transfer smolt, transfer market fish to slaughter, sea lice treatment for production fish, and as a work platform, all in the same week. Relying on adequate disinfection between events cannot be justified unless strict protocols are adhered to *every* time there is a change and even then it remains a practice with a relatively high probability of failure.
2) Indications are that boat traffic (including harvest vessels) that results in multiple site visits is a risk factor for disease transmission even in the absence of stopping at the site (e.g. see McClure *et al*., 2005)

3) Harvest practices that incorporate live holding of salmon in cages at the point of slaughter allows opportunities for disease spread (as identified for ISA transmission by Munro *et al.*, 2003)
4) Proximity to slaughter plants, especially when effluent is not disinfected (e.g. as identified by Jarp & Karlsen, 1997) is a risk.
5) Sharing of marine landing points (e.g. wharfs) can allow for transfer of pathogens. Whenever there are multiple activities crossing the same location, disinfection or environmental reduction (e.g. UV radiation) of the risk is required to reduce the probability of transfer to the next transfer 'vehicle'. This is a particularly challenging factor since the investment required for such large infrastructure takes time and sometimes there are no immediate alternative solutions.
6) Dead fish have a high probability of containing pathogens and delayed removal of fish from the cage increases the risk that they will be cannibalized or deteriorate sufficiently to release large numbers of bacteria or virus particles. Mortality disposal from the site must be done in such a way as to minimize the probability of contaminating other sites. During disease outbreaks when large numbers of mortalities are generated and when it is most important to contain the risk, mortality disposal can be extremely challenging.
7) Sea lice are implicated in the transmission of some viruses with ISAV being the most frequently cited example (Rolland and Nylund, 1998) and lack of sea lice control has been linked to increased risk of ISA transmission (Hammell and Dohoo, 2005b). Therefore, their control becomes part of a biosecurity plan.

The aforementioned basic principles of biosecurity have been established from experience and basic principles rather than rigorous generated evidence of their effectiveness. Identifying optimal prevention strategies requires knowledge about the epidemiology of disease outbreaks. Epidemiology studies are usually larger in scale (involving large segments of the industry) and costly to carry-out, but reflect the real world relationship between factors that can be managed and the mitigation of risk for introduction and spread of pathogens. These studies have become more frequent in the past decade but there is still a general lack of information regarding the dynamics of disease occurrence at salmon farms. The interaction of wild fish and environmental factors related to farmed fish disease, and those factors related to wild fish disease, remain huge challenges for industry and governments to facilitate.

Disease prevention can also be achieved by changing the susceptibility of the host to key diseases. Over the long term, susceptibility can be reduced through genetic selection. However, genetic selection has only provided partial relief in most instances. The most efficient method for improving resistance to disease is to modify the host immune response through vaccination. Vaccines for viral diseases represent the greatest need and also the greatest challenge for fish farmers. Inactivated viral vaccines appear to provide protection (e.g. Jones *et al*., 1999; Saksida, 2006) but are perceived to generate lower levels of protection than vaccines for bacterial diseases. DNA vaccines are being developed (e.g. Garver *et al., 2005*; Mikalsen *et al.*, 2005) and one DNA vaccine is licensed for use against IHN virus infections in Canada.

Treatment of infectious bacterial and parasitic diseases on a farm requires serious consideration of the potential economic impact on production, the environmental consequences of any drug used, the timing and delivery of drug to the fish, and the probability of detrimental side-effects for treated animals and consumers. Currently, there are no viable chemotherapy options for viral diseases. Antimicrobial drugs and chemicals are available for many of the bacterial diseases and a few protozoan parasites. Readers are encouraged to review the Chemical Inputs Report for further details regarding chemotherapy usage and the Sea Lice Report for details of sea lice treatments. This report will restrict comments to the logistics of using treatments effectively.

There are many issues that affect the decision as to when and how to use antimicrobial drugs to treat diseases on farms. One issue involves the practicality of delivering the drug to the infected fish. Antimicrobial drugs must be delivered in a manner that allows absorption and distribution to the appropriate tissues in order to reach therapeutic levels in the fish. Essentially, the fish can be immersed, fed, or injected with the treatment. Immersion methods are useful for such treatments as formalin baths for Ichthyobodo gill infections in hatchery tanks but are rarely used for marine net pens because of the expense and stress to the fish. However, bath treatments are used for sea lice infestations. Oral delivery in the feed is the most commonly employed delivery method for antibiotics. Injected treatments are reserved for smaller numbers of fish, such as broodstock, which can be handled individually. Injections of large numbers of production fish is possible (e.g. injectable vaccination) but injecting antibiotics as a treatment in a disease outbreak situation is expensive and problematic since handling and anesthetizing fish during their pre-clinical phase would likely cause more harm than benefit from the injection.

A second consideration is when to treat fish. Sick fish will quickly lose their appetite and cease to feed; therefore, the decision to treat orally must be made as early in the outbreak as possible to have the maximum number of fish actually consume the treatment. It is possible that sick fish off feed prior to starting the treatment can become moribund and die at the end or after the end of the treatment period. These fish continue to release infective bacteria into the water column until they are removed by the farmer. The therapeutic level in fish that ate the medicated feed will start to wane after the last day of treatment (rate depends on the drug and host metabolism factors) while the exposure to infective fish continues. As a result, it is very important to continually assess the therapeutic response by closely monitoring mortalities and moribund fish.

Timing of treatment also needs to be considered from a food safety perspective. The long withdrawal periods dictated for some drugs in some jurisdictions creates havoc with the management of other diseases. For example, withdrawal times (the time between the last treatment and when a fish can be shipped for slaughter for food) in Canada for oxytetracycline can be as high as 180 days when water temperatures are cold. This long withdrawal period will motivate farmers who are cautious about a viral disease outbreak (i.e. ISA) that may require immediate depopulation to second-guess the need for treatment. Should early harvest be required to prevent the spread of the virus, the fish are not permitted to go for human consumption due to antibiotic residues. Hence, some antibiotic treatment decisions may be delayed until more fish have gone off feed due to illness while the site managers wait to see if the disease will be sufficiently severe to require treatment. As with many fish health management issues, treatment decisions are not always straightforward and require informed consideration of risk.

Efficacy of treatments can be assessed based on mortality patterns and cumulative growth, but large datasets are required to detect changes due to treatment relative to the many other variables that naturally change over time in fish farming. Outcome measures that might be based on harvest weights are difficult to interpret since different harvest dates and partial harvests (i.e. only a subset of the cage is harvested at one time) will severely restrict the quality of the data. Farmers are rarely willing to forego treatment in a blinded, randomized control trial when the efficacy is generally accepted even though much of the evidence to support its use was not generated using blinded, randomized control subjects. This limits the scientific basis for the selection of methods for most appropriate and effective disease treatments.

Disease control practices for industry-wide diseases are often based on what ‘should’ work rather than what is ‘proven’ to work in those circumstances. The responsibility to decide and finance properly designed randomized field trials is usually in the hands of industry (i.e. government will assist if there is an industry funding partner). Unless the industry makes a collective decision to support these kinds of trials as a group, too few rigorous trials will be implemented to identify worthless versus effective treatments. The benefit of reduced treatment or vaccine costs is too small an incentive compared to the large cost of uncontrolled disease. Although these field trials can be large and expensive, they also provide huge benefits to the consumer and general public regarding judicious use of chemotherapies in the aquatic environment.

Setting meaningful and broadly applicable standards for treatment of disease will be hard because of these and other considerations. However, some general requirements such as adequate access to veterinary services to ensure proper diagnosis and planning of treatments can be recommended and are already legislated in many jurisdictions. Well supported diagnostic facilities and a logistic plan for response to a disease event should all be part of a farms operational plan.

4.1.3 Measure effects of disease and disease control

Quantification of the effect of disease on the productivity, as measured in growth and feed conversion efficiency, is a seriously neglected area of study. The reasons for this neglect are not lack of interest but lack of reliable methods to investigate them at the farm level. It has historically been assumed that disease realizes its main effects on morbidity and mortality and, therefore, can be measured in the lost revenue of deaths and treatment costs. However, it is generally accepted in terrestrial livestock production that the effect of disease on growth and efficiency can be far greater than the cost of mortalities, particularly when the prevalence of chronic subclinical infection is high.

Investigating the impact on growth and efficiency is complicated by the fact that fish farmers deal with hundreds of thousands of individuals at a site and tens of thousands in a single production unit. Fish have highly variable growth rates and patterns within each production unit and active sampling must be done to measure their growth. Representative sampling is difficult at best, especially when sampling can be biased by healthier, more food-aggressive fish being included in a sample that uses food as bait for capture (the most convenient method).

4.2 On wild fish

As with farmed fish, there is a wide spectrum of health represented within wild fish populations. However, in the wild, fish at the 'poor health' end of the health spectrum are removed from the population much more quickly than at farms due to the challenges of predation and foraging faced by sick fish. The efficiency of growth based on local food availability is likely more important to survival in wild circumstances than when presented with an abundant supply found in farms.

It is beyond the scope of this report to delve into the many factors related to salmonid survival in the wild, but some important considerations in which salmon farms may alter natural disease events and the difference in approach to the science of fish disease for wild fish versus farmed fish will be discussed. The primary objective of this section is to describe ways to measure the potential impacts of disease and options to reduce disease impacts (from any source) on wild fish (sea lice comments are purposefully excluded in this report to minimize duplication with the Sea Lice Report).

Environmental conditions fluctuate greatly from year to year presenting greater or lesser challenges to growth and survival of wild fish (Noakes et al., 2000). This has the potential to generate huge changes in the 'population-at-risk' for disease outbreak events. If exceedingly large populations enter into an environment that normally has the capacity for a fraction of this group, natural balancing forces are initiated, although slightly delayed. The number of predators is likely to rise in response to the increased food supply and the food supply for the salmon juveniles is likely to be taxed causing the lower health segment of the population to have additional nutritional challenges. As the number of less fit individuals rises in an area, they may begin to inhabit the margins of their natural aquatic ecosystem where they are more likely to encounter extreme water quality conditions at shallower depths, such as fluctuating water temperatures or salinity. Based on our knowledge of disease under farming conditions, fluctuations in such parameters are more likely to lead to infectious agents being advantaged and clinical disease occurring (for example, Jarp *et al.*, 1994, described sites that had daily fluctuating salinity associated with greater frequency of disease outbreaks). Clinically diseased fish are more likely to be preyed upon or fall behind the migrating group, removing these individuals from the population. Thus, it is possible that greater natural numbers of juveniles in any given year may contribute to a greater total number, and possibly a greater proportion, of the unhealthy fish of the population actually succumbing to clinical disease and predation. However, it is critical to note that this scenario is speculative. There are no conclusive studies of the dynamic relationship between changes in wild fish population ecology and risks of disease, especially from diseases on marine salmon farms. Although there are many ecologists and wildlife disease experts around the world, few are working on the disease dynamics in wild salmonids. Too frequently, the disease experts working on wild salmonids and disease experts working on farmed salmonids do so in isolation of each other.

Another important difference regarding wild fish population disease dynamics is the constant removal of clinically sick fish by predators (Mesa et al., 1998). The effect of this early removal is to reduce the duration that an infected fish will co-exist with susceptible fish and thereby reduce the effective contact required for transmission of the disease agent. Simplistically, the number of new infections that each infected individual can cause is lower (Reno, 1998). The most likely diseases to continue to spread are those that infect fish but cause insufficient detriment that the host continues to live with its cohorts for longer effective contact times. Alternatively, some disease agents have such a short effective contact time required to transmit infections that disease spread can occur prior to the host's removal by predators. Sick fish, in contrast, at a salmon farm tend to remain with the group as it moves around the circle of the pen, thus increasing the effective contact with many more fish. There are several episodes in the life history of wild salmonids in which densities can be very high (Reno, 1998). Patchy distributions, especially in freshwater life stages, cause densities to vary by ecosystem and life stage which will affect disease transmission potential for wild salmonids and introduce more uncertainty in disease risk models (Reno, 1998).

Mortalities caused by infectious disease in wild fish are rarely observed except when the absolute numbers of mortalities overwhelm the natural scavenging capacity of the location such as occurred in the herpes virus outbreak in pilchards in Australia (Whittington *et al.*, 1997), the VHSV outbreak in pilchards and herring in British Columbia (Traxler *et al.*¸1999), or *Gyrodactylus salaries* in wild salmonids in Norway (Johnsen and Jensen, 1991). This is not to say that infectious diseases are not part of natural populations (e.g. Traxler *et al.*, 1997) and may form part of natural population control mechanisms (Reno, 1998; Bakke and Harris, 1998), promoting the demise of infected individuals through predation or through the disease itself. Rather it means that these events tend to occur in locations where they are not available for human observation. Infectious disease has been identified and studied in wild salmonids for many decades with many examples in the scientific literature available for furunculosis, bacterial kidney disease, VHS virus, IHN virus, and so on. Documentation of disease in wild fish is usually focused on massive mortality events or on surveys, such as done by Kent *et al.*(1998). Enhancement hatcheries also provide an opportunity to investigate many aspects of diseases that occur in returning broodstock or vertically transmitted diseases, particularly BKD in western North America (e.g. Noakes et al., 2000, or Hamel, 2005).

4.2.1 Monitoring / surveillance (presence, levels, and patterns) in wild fish

Surveillance for infection in wild fish requires a large commitment of resources for which there may be little direct return on investment, even when a large commercial fishery exists. Many infectious diseases have been detected in wild fish (e.g. more than 225 infectious agents were tabulated by Bakke and Harris, 1998), but society does not routinely interfere with natural processes of disease in wild populations. Recently, three primary stimuli have increased interest in surveillance of diseases in wild salmonids: 1) potential for interaction with farmed salmon diseases, especially sea lice, 2) international trade regulations blocking imports that lack evidence to support claims of disease-freedom, and 3) climate change affecting the infectious disease pressures facing wild fish populations. However, the ongoing expense of disease testing in wild fish must come from governments and, with some exceptions like Norway, many are unwilling to commit the adequate resources for an ongoing surveillance program in wild fish, except to satisfy the public outcry for some hot topic issue of the day. Surveillance tends not to be systematic and ongoing, but rather 'one-off' surveys focused on a specific pathogen, place and time. This lays at the heart of the many unknowns and uncertainties regarding the role of disease in wild fish and the relationship between diseases in wild and farmed fishes.

Proving a wild population to be free of specific diseases is a very difficult hurdle to overcome. For programs on farms, provided there are no positive test results in this type of sampling scheme, the population can be assumed to be free of that disease agent (with varying levels of error due to chance based on sample size) (see Surveillance Chapter of the OIE Aquatic Animal Disease Code, 2008, for detailed description and assumptions of this process). However, surveillance to estimate infection prevalence usually depends on diagnostic testing done on random samples from the target population. The opportunities to sample wild fish, let alone random sampling, are sporadic at best. The most convenient and least expensive opportunity is to sample during a commercial harvest. Although random samples o the harvested fish are possible during the commercial harvest, this is a subset of the population of interest represented by the survivors that reached the age/size suitable for harvest. Other opportunities to sample fish in their natural habitat are rare but occasionally accomplished in such situations as when they are concentrated in rivers (e.g. electrofishing of pre-smolt or returning spawners, as done by Plarre et al., 2005). Sampling healthy fish for disease agents is much more problematic for detection even when the pathogen is present (Nérette *et al.*, 2008) due to the expected low prevalence and the small quantity of pathogen in tissues. Pooling of samples from more fish to evaluate low prevalence diseases is an option but the effect of pooling (e.g. dilution and potential for contamination, see Muñoz-Zanzi et al., 2006, for description of effects) has rarely been examined for fish diseases. Obtaining an accurate disease picture, especially at different stages of the natural life history, of wild fish is very challenging.

Monitoring survival in wild fish populations provides insight into cumulative mortality for all causes, the overall crude mortality, but gives very little information regarding the specific causes. Many factors influence the survival of wild fish, particularly migrating populations like salmon, such as large scale ocean conditions, climate, and predation (e.g. Coronado and Hillborn, 1998) and Beamish and Mahnken, 2001). The reliability of estimating the magnitude (or the probability of error for the estimate) for the isolated impact of infectious disease is questionable when the background mortality rate is highly unpredictable. It is understandable then that the few disease models that have been developed for wild fish populations focus on general conclusions about system dynamics rather than estimating individual parameters requiring time series observations (Patterson, 1996). Identifying increases or decreases in overall survival proportions over time requires that reasonable estimates of population-at-risk numbers be available. For the component of the wild fish population being investigated, which could range from all fish species in an entire region to subsets of certain watersheds when investigating salmon survival, reliable details of at-risk numbers are rarely available.

Models of disease effects on the abundance of wild populations are generally complex but contain sparse data inputs (Patterson, 1996). Ecological factors can be associated with overall group mortality but distinguishing exposure patterns within the large group must be based on many unproven assumptions. Survival in most wild populations will be affected so predominantly by the local environment that the primary conclusion is that the ‘local environment’ factor influenced survival. The goal of determining the impact of a specific factor, such as the influence of the local salmon farm, within this population is frequently unanswerable.

In most situations, particularly for endemic disease, the objective of surveillance is to identify trends whereby prevalence of disease changes spatially or temporally. That is to say, is the disease having a greater or lesser impact in some population segments or during some periods of time than others? In this way, the dynamics of infectious processes in wild populations and the potential external influences, including anthropogenic, can be better understood. Prevalence estimates for disease in wild populations is particularly difficult to obtain. As stated previously, biased samples can used to support statements about the presence / absence of disease. However, these non-random samples are dangerous to use as estimators of prevalence except when limiting the inferences to that component of the population and not the general population. For instance, obtaining fish at the margins of their natural ecosystem because they are available, even if a random selection process is made within this group, is only a sample of the part of the population driven to exist on the margins of optimal environment. This type of sample does not represent the general population anymore than taking the smallest, slowest fish from a net pen and then inferring the disease prevalence at the entire farm (or area of farms) based on the proportion of infected fish in this sample. Work done by Stephen and Ribble (1995) revealed the misinformation that can come from just such a practice.

An important consideration for potential disease introduction to an area is that migrating populations of salmonids have some opportunity to cohabit with migrating populations from other locations in the world when in the open-ocean (e.g. Western European stocks mixing with Eastern Canadian stocks in the North Atlantic). This represents some unknown level of risk for pathogen exposure and subsequent transmission across jurisdictions. Thus, introduction of new diseases to an area is possible through this source though the actual magnitude of risk is extremely difficult to quantify.

In conclusion, infectious diseases are commonly identified in wild salmonids around the world. However, the patterns of disease transmission within, and between, wild fish populations are largely unstudied due to the complexity of the interactions and the large natural fluctuations in survival. Data to support disease models is usually too sparse and questions at the detailed level of subsets of fish populations, such as within bays or fjords, cannot be addressed adequately without a much greater effort. Monitoring survival and cause-specific mortality requires a large commitment of resources but it remains doubtful that the desired level of detail can be obtained with current surveillance techniques.

Chilean Case Study

Details on programs and procedures used to prevent, control and treat disease in Chile

Farmed fish

Monitoring / surveillance (for early detection, presence, absence, patterns)

Infectious diseases are monitored in Chile in the following ways. Private salmon companies regularly monitor fish disease status on a weekly, bi-weekly and monthly basis. Most of the salmon companies employ their own veterinarians. Only a very few of companies receive external veterinarian technical assistance (private laboratories), most of them visiting hatcheries. At each farm site the same veterinarians are in charge of analyzing information on the sanitary conditions and fish production records. They carry out necropsies and classify the mortality according to the apparent cause based on external and internal lesions (they may also train divers and field health assistants to do some classifications). Depending of the mortality rates, they take samples and send them to the laboratory, decide on the strategies for response, and write technical reports and certifications for the Health Department, Executive offices in the company, National Fishery Service, Salmon Industry Association (Intesal), and insurance companies.

Samples from dead or sick fish are sent to a diagnostic laboratory. This may be the company's own laboratory (the exception) or private diagnostic laboratories. For several years, Intesal has had an Epidemiological Surveillance Plan for each geographical area. They produce reports for companies in each area for the diseases present and analyze productive records. Every three months they meet with the companies (farm sites) of each geographical area (10) and a consolidated report is made up with the sanitary, production and disease trends.

There are five government surveillance programs (details can be found at http://www.sernapesca.cl/index.php?option=com_content&task=view&id=73&Itemid=185). The first is the Epidemiological Surveillance Active Program. Twice a year, a directed, random sampling strategy is carried out on all of the farm sites (freshwater, estuarine, and marine). It is mainly focused on detecting diseases that are exotic to Chile – (EHN, IHN, VHS, OMV, SVC, Viral Encephalopathy and Retinopathy, CCV, Enteric Septicemia of Channel Catfish, White Sturgeon Iridovirus, Pancreas Disease, Furunculosis). The samples can only be taken by authorized external veterinarians from the diagnostic laboratories approved by the National Fisheries

Service (Sernapesca). The Diagnostic Laboratories that process the samples are accredited by Sernapesca. These Laboratories are strictly and regularly audited and supervised by Sernapesca. There is an established legal procedure for carrying out the sampling and for the laboratory analysis (NT-10).

The second program is the Epidemiological Surveillance Passive Program. The results of routine diagnostics carried out by private diagnostic laboratories to detect infectious pathogens must be reported to Sernapesca every month, classified by geographical area without identifying the farm site or the company, except for Streptococosis (*Streptococcus phocae)* and Atypical Furunculosis (*Aeromonas salmonicida var achromogenies)* where the farm site must be indicated.

The third surveillance program carried out by government is the Broodstock Screening Program. It is mandatory for all of the broodstock, whether salmon or trout, that is going to be spawned in the country, to be assessed for BKD, IPN, and ISA, by using one or more of the following laboratory techniques: (i) for BKD: IFAT, ELISA, PCR; (ii) for IPN: RT-PCR, cell culture; and (iii) for ISA: RT-PCR. Practically all of the companies requests RT-PCR (PCR) for BKD and IPN. The use of PCR has replaced cell culture almost completely. All males and female broodstock are tested for IPN and ISA while 100% of females only are tested for BKD. All of the eggs belonging to positive parents should be eliminated under the supervision of an approved veterinarian. Each egg batch should be disinfected by iodine twice: as green and eyed egg.

Broodstock are assessed for ISA by using RT-PCR since 2008. If during spawning a broodstock is detected for being positive for ISA the eggs are eliminated, a certificate is written up for the elimination, and it is mandatory to analyze the lot during the early stages of development (twice).The legislation proposes other elements, but they are under discussion. Piscirickettsiosis (SRS) testing can be included, but it is optional.

The fourth program is the Contingency Program for the ISA. Compulsory legislation prescribes surveillance in geographical area under suspicious and under quarantine as well as in ISA “free” areas. Farm sites that are in the quarantine area are those sites that fall within the 5 km radius of an ISA positive site. Suspicious farm sites are those that are geographically and epidemiologically related to the quarantine sites. All of the fish that are being transferred between fresh water sites or from freshwater to brackish or sea sites farm have to be monitored for ISA. All of the positive monitoring results are recorded in the Website of Sernapesca The positive farm sites are therefore public knowledge. Regulations are adapted and delivered to the industry when there are new advances, new challenges, new critical points and aspects under re-consideration, among others.

The final program involves official studies for suspected exotic or emerging disease. Funding comes directly from Sernapesca. Sernapesca contracts a private lab or university lab according expertise to carry out the studies. These kinds of official studies were uncommon in Chile in the past but are becoming more frequent recently (e.g. Hemorrhagic Smolt Syndrome HSS, Jaundice Syndrome, and now ISA and PD research in progress).

Agreements are in place within Intesal that create an Integrated Formality System Program (SIGES). One of the many features of this program is that the farmed fish should be regularly monitored, a sanitary history and classification should be kept as well as the mortality recorded according to the apparent cause. The associated companies are obligated to keep this agreement. There are three Programs carried out by Intesal: (i) Caligus (sealice) Program, (ii) Phytoplankton Monitoring (FAN) and (iii) Salmon Health Management Program . The cost of diagnosis and control is 100% paid by the producer, except for the Official Studies.

Salmon companies in Chile record and evaluate the following parameters every day as part of their own monitoring and surveillance programs:

Appetite and Feeding Behavior	The amount of feed consumed daily and observations on their feeding behavior is recorded. The majority of the companies use automatic feeding or semi-automatic. Most of them are controlled by video or computer system.
Environmental Parameters	Variations in water clarity, salinity, oxygen and temperature are recorded and analyzed to see how appetite is related to environmental changes. Analyses are carried out by Intesal

	and results are reported to companies.
Phytoplankton.	The kind, quantity and quality of the phytoplankton detected at defined marine recording stations are recorded and compared to historical records.
Mortality	Dead fish are removed daily. In some lakes and in all brackish water and sea water divers remove the dead fish. An apparent cause of death is records, usually using these criteria: "without apparent cause", predators, mechanical trauma, osmoregulatory maladjusted (stunt) and deformed. This classification is carryied out by Veterinarians or/and secondary health assistant previously trained. An increasing number of companies include suspect diseases such as (SRS, Vibriosis, IPN, Exophiala, BKD, Atypical Furunculosis, etc).
Morbidity	Moribund fish are extracted by using traps (nets) in estuarine and marine sites. The recently dead and sick fish are regularly analyzed in the field (necropsy) and in the laboratory. This helps the Chilean industry implement an early detection system to find carrier stages or prior to outbreak.

In general, the frequency of classifying dead fish as "without apparent cause" has become less frequent as companies seek to understand better their health problems on farms. Intesal is carrying out a consistent action plan to elucidate the real causes of mortalities. They are meeting monthly with companies to improve the cross-information and "without apparent cause" classification is one of the points discussed. Field investigations of non-specific causes of death as well as passive and active surveillance for specific etiological agents support these efforts.

There is no specific threshold provided by law to define an outbreak. Intesal, in their Health Plan for the industry has agreed to define an outbreak as when a specific cause of mortality rises above the 0.5% of the monthly mortality. Veterinarians and lab personnel may start investigations prior to this threshold being reached. Fish health personnel use multiple methods and diagnostic criteria to support strategic decisions including fish behaviour, mortality records, field findings, and laboratory diagnostic results. This approach has facilitated early diagnosis and quick response to control the outbreak and has now become routine.

There is no formal difference in case definitions used between regions within the country and OIE definitions serve as the foundation for final diagnoses. There remain some issues regarding how different types of results are interpreted differently and thus affecting the decision quality. For instances: IFAT vs PCR; conventional PCR vs qPCR; clinical diagnosis vs lab diagnosis can all influence how an investigation is assessed within companies.

Diagnostic Support

Laboratory staff are generally well qualified. The accredited Chilean diagnostic laboratories making official diagnosis have a very good technological level, precision, objectivity and consistency as well as trained personnel. There are permanent training program in each laboratory, with specific training at national and/or international level using private or public co-financing. Chilean private laboratories are routinely applying the most advanced diagnosis technologies, like PCR, RT-PCR and qPCR and in some cases genetic sequencing. The private laboratories that work with formal contract with the aquaculture companies are authorized by Sernapesca. They comply with a series of requirements on technical aspects, infrastructure, skill and qualified personnel. The laboratories are accredited by a standard for the PVA (NT10) and quality standards are being implemented for each laboratory (ISO.17025) which are certified by a government agency, the Normalization National Institute. There is a certain time limit for implementing this standard. The diagnostic methods used should be accredited and standardized. Close to the end of 2009 (or early 2010) the diagnostic techniques used in official programs must be validated according OIE criteria, through official validation government agency (INN). The validation process has some important difficulties due to its complexity and need to rely on positive controls (it is prohibited to enter exotic live agent into the country). They are now adapting the process in order to comply with these standards.

The sensitivities of the diagnostic methods used have been established using an international reference. However, each laboratory must soon use local validation results as part of implementation of ISO.17025. This process will hopefully improve the sensitivity of the methods. There is some research being done on the sensitivity of the diagnosis of certain methods and comparison (i.e. IFAT; IFAT vs. ELISA, IFAT vs. PCR, cell culture vs. PCR, PCR vs. qPCR, Taqman vs. SybrGreen Real Time PCR). None of them have been published.

The Surveillance Health Program of exotic disease is carried out using a Chilean rule NT-10, which it was established taking in consideration international criteria but with a local adjustment due to the prohibition of importing exotic virus to the country (e.g. VHSV, IHNV) for use by the diagnostic laboratories. This authorizes the possibility of not using positive controls when testing. The ISA Contingency Program is carried out using only the technology and reference RT-PCR Taqman. Other technologies are not legally allowed. The ISA Contingency Program and all diagnostic carried out for ISAV should run a Ring Test (RT-PCR Taqman) in an OIE International Reference Laboratory to be legally accepted. Chilean uses the OIE laboratory located in Canada (UPEI, Dr. F. Kibenge). In the case of the Screening Broodstock Program, there are various diagnostic techniques accepted (such as IFAT, cell culture, RT-PCR, ELISA), however, the technique and target organ or tissue could change and be governmentally accepted if a series of scientific studies are conducted and delivery to Sernapesca showing a good correlation and consistency with the approved diagnostic methods

Chilean law makes a clear difference between exotic and endemic or enzootic pathogens regarding their surveillance programs. Active surveillance programs focus on exotic pathogens while passive surveillance is used for endemic diseases. If an exotic agent is detected during a routine diagnosis, the laboratory and the company are obligated to immediately report this to Sernapesca, even if the diseases is only suspected and not confirmed. Once notified, an investigation and movement restrictions are enacted.

Drug Treatments

All treatment product used in aquaculture must be registered by Agriculture and Animals for consumption service (SAG). Most antibiotic treatments are based on previous in vitro drug sensitivity test. Success in treatments is gauged by changes in mortality patterns and laboratory confirmation of the reduction of the pathogenic agents. Pharmaceutical companies have conducted clinical trials, even though are not officially requested, to help inform treatment decisions. Some studies have been performed on in vitro sensitivity testing to specific pathogens which are used to improve drug use strategies. Some pharmacokinetics studies have been conducted by pharmaceutical companies.

Veterinary prescription is required by law. Without veterinary prescription, the feed manufacturing plant can not delivered medicated feed to the companies. A legal declaration of the withdrawal time is strictly requested by processing plant prior slaughter and process. Official sampling for detection of residues in live fish prior harvest to export product is required.

In Chile, Aqua-Vets are responsible for the prescription and calculation of treatment regimen, management of the therapy (according to body weight and feeding rate), evaluation of product supplier, traceability, recording, sending the treatment information to Sernapesca, coordination of the sampling to residues analysis, medicated diet sampling to perform assay and to check the amount of active compound in feed.

Feed companies have internal procedures to incorporate drugs into the diet based on pre-determined doses defined by discussions between the feed plant and veterinarians The feed plants must respect legal procedure and have in place strict biosecurity program and internal regulations for quality control. A high level of confidence exists nowadays in the safety and reliability of the medicated products. Optimal use of pharmaceuticals protocols have been developed according to the new Salmon Association agreements. The Chilean Salmon Industry via Intesal has made agreements with companies through a Technical Health Committee to establish criteria to use antibiotics, indicating maximum doses and time (see table below)

Registered drug	Administration	Doses (mg / BW)	Time (days)
Florfenicol	oral	20	14
Oxytetracicline	oral	100	14
Oxolinic acid	oral	25	14
Flumequine	oral	25	14
Oxytetracicline	injectable	35	
Florfenicol	injectable	35	

(BW: body weight)

Antiparasitic drugs are also used to control disease in Chile (see table below). The industry only used Emamectin benzoate until summer 2008 when other products began to be used under special approval to provide an alternative treatment strategy due to development of resistance of the sea lice to Emamectin benzoate. A National Sea Lice Control Program was developed by SalmonChile and was recognized by Sernapesca. It is now an official program that has been successful in reducing sea lice.

Chilean antiparasitics:

Registered drug	Administration
Emamectine Benzoate	oral
Deltamethrim	bath

The Chilean industry uses immunostimulant products delivered through feeding and mainly during transfer the fish to seawater to increase immune responses. These products are easily accessible by companies but their cost/benefit ratios have not always been determined.

Stress reduction is also advocated in response to disease problems. Standard measures on farms include: (i) Stop feeding, better control of feeding , (ii) Avoid handling; (iii) supplemented diet containing immunomodulators; (iv) Monitoring water quality in freshwater and during transport; (vi) reduced size dispersion; (vii) Control of predators, (viii) Avoiding overcrowding; and (ix) Low densities at transport.

Stocking densities as risk factor for pathogen transmission (within and between farms)

The increase in sea lice and ISA outbreaks during 2007, resulted in a reduction of sites in production in those areas with higher density, specifically Chiloé Island. The stocking densities in the Chilean industry have been diminishing, especially as part of control of ISA and the need to optimize the practices of rearing and managing. At present, agreements exist between the privates companies through the Association of the Chilean Salmon Industry (SalmonChile), to avoid stressors that increase the susceptibility to infectious diseases. This agreement represents a commitment by private companies. This stocking density during grow out does not exceed 10 Kg/m3 for coho salmon and rainbow trout; being able to come to harvest at maximum level of 15 Kg/m3. For Atlantic salmon the maximum level during grow out is 15 – 18 Kg/m3; not exceeding a stocking density at harvest time of 20 Kg/m3.

Other relevant changes in recent years include; (i) increasing cage size which reduced the number of cages per site; (ii) reduction of the sites in production for official regulation (specifically ISA); (iii) prohibition of smolt transfer in quarantine zones; (iv)reduction of sites in production due compulsory early slaughter or stamping out efforts for ISA; (v) reduction of biomass in production due the ISA infection (early slaughter causing reducing weight to harvest) and (vi) restriction in the license delivery in southern area due to conflicts with tourism, inhabitant disagreement and NGOs concerns.

The industry is now reorganizing under the concept of clusters in a geographically shared area, as a way of unifying management criteria especially as it relates biosecurity. This scheme involves all industry participants.

Smolt transfer from freshwater to sea water

Diverse management and handling procedure are involved in this phase of production. The introduction of year class smolts in the grow-out sites must be in a maximum period of 4 months during 2008 (a reduction in following years to 2 or 3 months is expected). A compulsory sanitary certification is required to move smolts. To ensure smolts are physiologically prepared for transfer companies check of gill-ATPase test is applying as well test water salinity. Companies influence smolt production in hatcheries with recirculation system or open-flow to increase the smolt quality, reduce the fungus disease and environmental impact.

A Chilean Salmon Industry Agreement recommends vaccination of 100% of Atlantic salmon (against IPN – Vibrio) and rainbow trout (against IPN). SRS was not included because of concerns over vaccine effectiveness. Some companies are using biotechnological products to improve the smolt quality, such as the use of diets with immunostimulant or immunomodulators (i.e. nucleotides, glucans, etc). Grading prior transfer is done to reduce the size dispersion and eliminated those fish with low performance. The use of rearing sites in lakes and estuaries has been reduced in recent years. Instead there has been am increasing use of rearing of early stages in freshwater with recirculation systems.

Environmental quality as risk factor for pathogen transmission

An Environmental Regulation Program for Aquaculture (RAMA) was established some years ago. Baselines study are performed to establish the measures to protect the aquatic environment and to determine if aquaculture facilities may operate in accordance with capabilities of water body in lake, rivers and sea. The trend is to locate the net-pen out of the shore to get better environmental condition for culture and thus reduce diseases and increase productivity. After receiving their aquaculture license companies identify the best location of pen-site based on environmental specific analysis to obtain the best condition as possible to get better productivity. All production sites (and hatcheries) monitor water parameters such as temperature, oxygen, transparency and salinity (hatcheries are increasingly measuring total gas pressure and heavy metals in inlet water due volcano activity).

Risk factor studies for health management measures

Studies related to the risk assessment for the introduction or spread of infectious disease agents has been scant in Chile. Risk analysis regarding introduction of imported eyed-egg have been done many years ago and must be updated in accordance with changes in the sanitary status of the countries providing eggs to Chile. The government has increased funding for research in diverse matters related to aquaculture, especially in fish health. This supports some epidemiological studies.

Risk reducing effects of disease control (wild fish)

There exist strict regulations regarding escape of fish from the culture because of concerns about possible negative impacts on the environment and wild fish.

In Chile, fallowing period at the regional level is not enforced. It is quite complicated to implement due geographically and hydrographically reason even though important efforts were started in 2008 through the creation of cluster in body water in which the disease risk are common to the companies involved in this area.

Efforts by the Chilean salmon industry and government to reduce the risk of disease are in course. There are response plans in place for when a disease is detected. These plans are expected to provide benefits both for farmed and wild fish sectors and include actions such as zoning, investigation, stamping out (depopulation), enhanced biosecurity, compulsory reporting, education, monitoring of wild and farmed fish, fallow periods, and control of fish transport.

Depopulation and fallowing to reduce environmental load and risk to wild fish

Chilean regulations include this topic as fundamental part of the Fish Health Management Program. This program is focused on salmon production to reduce the risk of pathogen transmission, however, it has collateral positive effect on wild fish and the environment. They are being applied in the Chilean Salmon Health Plan for ISA.

Wild fish

Wild fish disease monitoring is the responsibility of Sernapesca. More studies are needed to understand the relationship between farmed and wild fish in terms of the dissemination of causative disease agents. Many of the commentaries and arguments related to the health of wild fish presented in this document are applicable to Chile. Major studies should be realized concerning this matter, to provide more objective precedents for establishing integral disease detection and control strategies. The Chilean government is increasing the funding contribution for this type of studies. For example, the evaluation of the potential presence and characteristics of ISAV is planned in wild fish in the lakes of the Xth region of Chile.

Some examples of studies that have been carried out include: SRS in wild fish and biota (inside and outside of the cage) as possible reservoirs for infection; wild fish as potential reservoirs of Francisela (U2) infection in native fish (*Galaxia maculates*); and an evaluation of *Yersinia ruckeri* in wild cyprinids. It is compulsory in Chile to notify government officials of any unusual mortalities observed in wild fish.

Treatment or control is not considered practical except where enhancement practices are adopted.

Chapter 5: Disease Management Systems

5.1 Fish health/veterinary infrastructure

Access to health services is an essential part of any health management program. Timely and reliable provision of diagnostic and disease control services is critical for recognition, prevention and containment of infectious diseases on fish farms. This section provides an overview of fish health and veterinary infrastructure with comments on capacities in Norway, Canada, and Chile.

5.2 Diagnostic Support

Fish disease diagnostic laboratories and fish health support services exist at various levels wherever salmon farming occurs. Generally, government laboratories have been the first to offer diagnostic support to the salmon farming industry as it develops. By the mid-1980's, Norwegian, Scottish and Canadian salmon farmers could access the diagnostic capabilities of their respective national Departments of Fisheries. In almost all cases, these national resources had initially been developed for researching and monitoring of wild salmonid stocks motivated by the need to mitigate disease in the enhancement hatchery systems. Disease management has, and continues to be, a central component of salmonid enhancement. It is generally accepted that salmon farming was able to address many of the early diagnostic challenges because of the many decades of experience by government scientists and administrators in salmon enhancement. Early investigations and diagnoses of salmonid diseases depended on this wealth of experience.

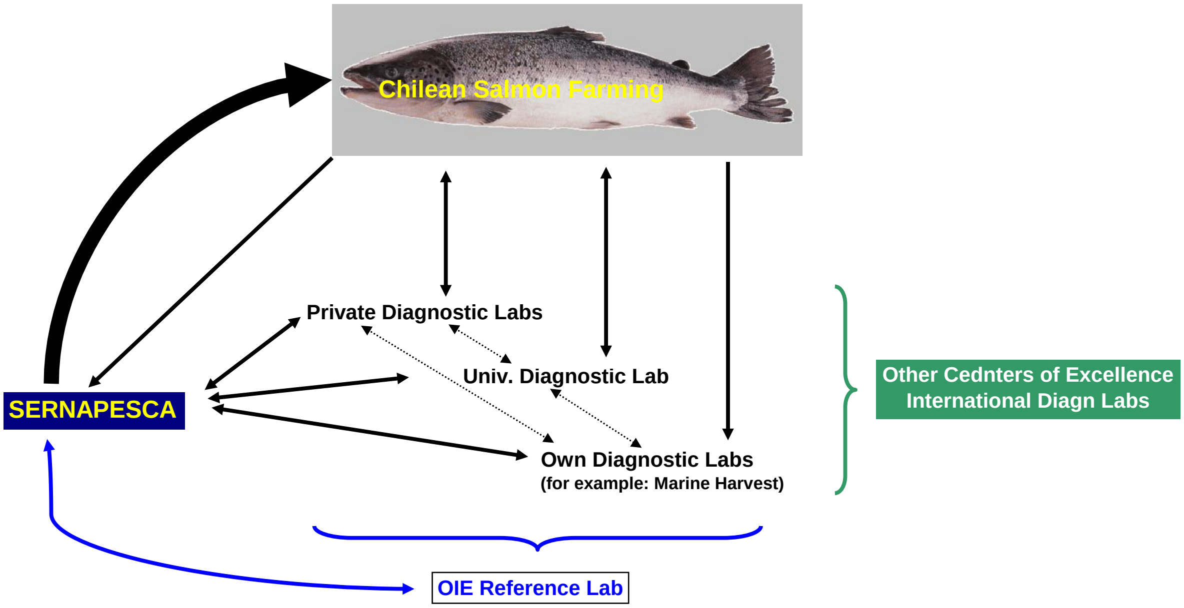
Today, the salmon farming industry has access to a wider suite of diagnostic services provided within a company, by private diagnostic laboratories and/or by government laboratories. Veterinary involvement has grown from being very rare in the early days of the industry to an essential component of disease control. The fish health team often has many members including health technicians working on farms, biologists working in academia or government, microbiologists and pathologists at diagnostic laboratories, international reference laboratories, and, of course, the farm workers who are the critical foundation of the team. Some examples of country specific details on diagnostic capacity follow.

Norway:

The Norwegian Food Safety Authority's mission in the aquaculture sector is to promote safe food, fish and animals, ethical keeping of fish and an environmentally friendly production. The food authority has offices throughout the country, close to the consumers and businesses. The food control authorities in Norway merged to form the Norwegian Food Safety Authority in 2004. At the same time 13 laws from relevant sectors were merged. The Act of Fish Diseases is currently administered under the Ministry of Fisheries as a part of the Food Law (from January 1, 2004). Norway has a monitoring system for specific fish diseases run by the Norwegian Food Safety Authority. Specialists employed by the Food Safety Authority together with private veterinarians and fish health inspectors are jointly involved in the monitoring programme. Further the state veterinary diagnostic laboratories (National Veterinary Institute) play an important role in the preventive health program. In addition to this, there are several private diagnostic companies and laboratories offering services to the aquaculture sector. Noteworthy is the pathogen screening employing real-time PCR methods that have come into general use since 2005.

Classification of diseases is carried out according to the specific Norwegian grading system (A, B and C-diseases). The Norwegian system will be harmonized in accordance with the regulations in EU in the near future. The diseases are reported on standard notification forms to the Norwegian Food Safety Authority and official reports are published annually.

Chilean Diagnostic Framework



Sernapesca has implemented regular and strict evaluations of diagnostic laboratories in accordance to international standards (e.g. OIE). Diagnostic laboratories are validating all techniques that are used in official programs (e.g. Cell culture, IFAT, PCR for causative agents, including BKD, IPN, ISA, VHS, IHN, EHN, OMV, PD) and are planning to implement ISO 17025 as compulsory measures (Dec 2009). This international standard focuses both on the presence of quality management systems for the laboratories as well as the technical proficiency of staff, methodology and testing equipment.

Not all diseases are reportable to SERNAPESCA. Fish farmers rely on clinical diagnostics carried out directly by private and university diagnostic laboratories to support their ongoing fish health management programs. Some fish farm companies have their own internal private diagnostic capacity as well.

The Chilean diagnostic laboratories maintain a close relationship with international diagnostic laboratories and experts. Rapid incorporation of new diagnostic techniques (often developed elsewhere) provides timely diagnostic capacity to face emerging disease. Technical workshops related to specific aquatic health and disease are carried out frequently (average 6 per year). Diagnostic personnel are offered frequent opportunities for continuing education both in Chile and abroad. Unfortunately, the number of scientific publications regarding the status of aquatic health in Chile is scarce despite the fact that new knowledge is constantly being produced.

Canada:

Private and government veterinarians are actively involved in on-farm diagnostic investigations (in Newfoundland and Labrador, Nova Scotia, British Columbia) or auditing farm health practices through regular visits (New Brunswick and British Columbia). Diagnostic laboratories to support marine cage culture and coastal salmonid hatcheries include provincial government diagnostic laboratories (incorporated into general agricultural diagnostic lab capacity in BC, or set up as separate fish health diagnostic labs in New Brunswick and Nova Scotia) or support provided through regional agreements (e.g. Newfoundland provides support for diagnostic costs when sent to labs in other provinces). Private veterinarians and farms can also submit cases to private veterinary practices for basic testing or at full service diagnostic labs at universities, the private sector and other large institutions. The federal Fisheries and Oceans Canada provides diagnostic laboratory support for wild salmonid surveillance as well as providing official laboratories for international reporting requirements. The Canadian Food Inspection retains the responsibility for international reporting of Canadian aquatic animal health status and uses regional diagnostic laboratories in Nanaimo, Winnipeg, and Moncton.

Scotland:

Clinical veterinarians in Scotland are either private (i.e. private practice providing service to salmon farms) or based within the larger companies. Diagnostic services are also offered through Institute of Aquaculture at the University of Stirling and Scottish Executive government regulatory diagnostic testing occurs through the Fisheries Research Service at Aberdeen.

5.3 Regulatory framework/Competent authority

5.3.1 Overview of relevant legislation

All salmon producing countries have policies in compliance with international bodies that are delivered according to national, and sometimes provincial, legislation. OIE reporting requirements are generally followed by every country and tend to dictate that much of the national level legislation regarding fish health is directed toward diseases affecting international trade. Supplementary regulations, sometimes at a provincial level, extend the legislative reach into other diseases that are not of trade concern but could have severe economic impact on industry, are of concern to public interests (including food safety) or generate environmental (including wild fish populations) concerns. Auditing is performed at local level and is carried out according to existing legislation. Some examples of country specific details on relevant legislation follow.

Norway:

The Ministry of Fisheries is the competent authority for issues related to salmon farming and is the competent authority to issue concessions. It is also the competent authority for veterinary services. The Norwegian Food Safety Authority has an overall responsibility for animal health and welfare in Norway, including fish health (www.mattilsynet.no/english/about). A set of regulations covers aspects from import/ export to preparedness in fighting animal disease. All fish farms are granted a concession on the basis of the Law of Fish Farming. A permit cannot be granted if the farm can potentially result in the spread of disease, potentially cause pollution to the environment or have a location that is clearly of distribution to the surrounding environment.

The competent authority in Norway for the conservation program from wild salmon is the Ministry of Environment. The regulatory framework is given by regulation of commercial fisheries (of salmon), cultivation programs for wild salmon and local inspection programs. Ministries of Fisheries, Agriculture and Oil- and Energy all function as competent authorities within areas that are of importance for the wild salmon. The regulatory framework that would appear as relevant are the Law of fish farming, Law of fish diseases, Law of water resource management, and Law of waterfall management (hydroelectric power).

The executing competent authority under the Ministry of Environment is the Directorate of Nature Management (DNM). DNM has established a cross-sector forum for anadromous salmonid fish with representatives from all competent authorities (as mentioned above) and in addition with representatives from local authorities (at county level).

There is also an international convention concerning the preservation of salmon in the northern part of the Atlantic Ocean. This convention is governed by the North Atlantic Salmon

Conservation Organization, NASCO, and includes all nations where Atlantic salmon is a natural inhabitant. NASCO was established to promote the conservation, restoration, enhancement and rational management of salmon stocks in the North Atlantic Ocean through international co-operation.

Canada:

In Canada, the competent authority for wild salmon conservation is the Fisheries and Oceans, Canada, (FOC) while the competent authority for all internationally reportable diseases is the Chief Veterinary Office within the Canadian Food Inspection Agency (CFIA). Prior to 2005, the FOC had sole federal responsibility for fish health issues. The few sections of FOC that were involved in fish disease research and support for salmon farms had no mandate to assist farms in diagnosing or controlling disease outbreaks, instead being focused on research or conservation matters. The dual mandate of enforcing legislation regarding wild fish conservation and aquaculture promotion was viewed by some to be a conflict.

The National Aquatic Animal Health Program was initiated in 2005 to address fish disease surveillance in support of international trade and is co-delivered by CFIA (policy development, implementation, and enforcement) and FOC (diagnostic laboratories and supporting research). It serves to bring the management of aquatic disease in line with programs and policies governing terrestrial animal disease and better coordinate the resources of both federal agencies. This coordination has resulted in improved response to diseases issues in Canada, as recently seen by the incursion of VHS virus into the Great Lakes. The Health of Animals Act gives authority to CFIA to fulfill this mandate. Legislation differs but agreements between federal and provincial governments lend power to provincial governments in some regional / provincial health issues (note that recent court cases have called into question the ability for federal government to assign these responsibilities to other government levels). Fish movements between provinces and between countries are under the jurisdiction of the federal government while movements of live fish between watersheds within a province are under provincial government jurisdiction.

Provincial legislation governing the licensing and operation of salmon farms provide a legislative framework to address fish health issues on farm. For example, British Columbia requires an annual inspection report from all marine finfish aquaculture sites and fish health is one of 4 targeted areas for reporting. It requires all companies to have approved fish health management plans. Many provincial regulations specify the need to retain health records and report specific diseases. BC, for example, requires mandatory sea lice reporting while New Brunswick does not require sea lice reporting.

Chile:

Private diagnostic labs and private salmon companies are compelled to notify national authorities when reportable, emerging or exotic diseases are found. The National Fisheries Service of Chile (SERNAPESCA) provides or ensures the capacity to diagnoses these diseases. It is responsible for certifying fisheries products and providing official fish health certificates. It authorizes a network of laboratories in the private sector, government and academia to conduct tests. The animal health unit manages a program for prevention, control and surveillance of high risk diseases. SERNAPESCA supports Chile's obligations to the World Animal Health Organization.

5.3.2 Fish health risk assessment capacity

International trade in aquaculture products falls under the purview of the World Trade Organization and the multinational body of expertise generated through OIE, the World Health Organization for Animals. Trade disputes associated with fish health require decisions supported by risk assessments. In addition, many nations have bodies concerned with the introduction and movement of fish which also rely on risk assessments. As such, Norway, the UK and Canada all have risk assessment capacity at a national level. Low staffing levels at national organizations have threatened the speedy completion of some risk assessments but the capacity is generally seen as being adequate. In addition, provincial bodies in Canada and larger corporations also employ risk assessment techniques for some fish health management decision making. Some jurisdictions have sponsored special risk assessments or environmental impacts assessments that have considered diseases issues. For example, the 1997 Salmon Aquaculture review in British Columbia contained an entire section on fish health issues. Recommendations from this review guided changes in provincial policies on fish health management and surveillance. Academic organizations and non-governmental groups have been responsible for publishing many papers striving to assess a wide variety of risks associated with salmon farming. It is unclear how they have been used to influence policy decisions at a governmental or private level, but they have contributed significantly to the body of science and opinion available on fish health issues.

Despite all of these resources for risk analysis, the lack of data and understanding of some of the fundamental ecological and epidemiological drivers of risk complicate the application of this methodology.

5.3.3 Company policies

In addition to public policy, corporate policies are increasingly regulating the management of fish health. Corporate policies can be very extensive and provide standard operating procedures for employees to follow in fish health management. Corporations are sometimes compelled to have their own policies to comply with existing regulations or in other times are seeking certification from a 3rd party to attest to the quality of their management systems. Such certification is sought to help avoid trade barriers, to improve profitability and to address public concerns regarding the safety of the industry and its products. International Standards Organizations (ISO) certification for environmental management is, for example, held by some BC salmon farms. The ISO's technical committee ISO/TC 234 was established in 2007 to develop standards for fisheries and aquaculture. It will serve to complement standards established by the International Council for the Exploration of the Sea (ICES), the World Organization for Animal Health (OIE), and under the United Nations: the World Health Organization (WHO), the Codex Alimentarius Commission (CAC) and the Food and Agriculture Organization (FAO). How it will address fish health specifically is unclear at the time of this report.

5.4 Systems management

Veterinary medicine in general and aquaculture medicine specifically, has grown from individual animal based medicine to the care and management of populations and systems. It is virtually impossible in salmon farming to manage individual animal health except for valuable broodstock. Gathering blood samples, monitoring physical changes over time and getting a health history for an individual fish is impractical and often impossible in commercial salmon farm settings. Instead, health management plans are based on a combination of clues from environmental changes (such as water quality), from fish group behaviors (like feeding) and from patterns of death or disease from samples of fish in a population. Biological factors are in turn integrated with regulatory requirements, economic constraints, practical and logistical considerations and community and company values when final decisions are made on how to prevent or respond to fish health issues. Such a “whole-farm” approach is consistent with herd health practices used for cattle, swine, poultry and other land-based agriculture systems.

The whole-farm approach extends beyond the border of the farm. As outlined throughout this document, movements of people, water and animals create connections between farms and between farms and wild species that are conducive to the spread and maintenance of certain diseases. Increasingly, farms are cooperating in the timing and methods for disease control to avoid the farm-to-farm sharing of disease as well as to reduce risks to wild fish. For example, sea lice treatment might be launched by multiple farms within a bay prior to the migration of juvenile fish to not only provide some protection to the out-migrating fish but also to reduce the burden of sea lice facing the farms. Another example includes coordination of the movement of feed boats and crews between farms to minimize the spread of infectious hematopoetic necrosis virus during outbreaks. Basing decisions on where to locate marine farms on knowledge of the location and movement of vulnerable wild species and information on critical distances to prevent farm-to-farm spread of disease is a final example of how considering factors beyond the farm-edge provides a means to reduce disease spread and thus disease prevalence. System-wide approaches to disease management are, however, only as strong as the weakest link. Should one farmer opt out of a coordinated and integrated disease management plan for a bay, many benefits are lost. In some jurisdictions such as Canada and Scotland, coordinated approaches have become commonplace to enable disease management across farms within a shared body of water. But these area agreements typically apply to a limited number of diseases under a limited number of conditions. Decisions to apply disease management options typically take into account cost /benefit calculations by the farmers. The threshold where the disease management costs experienced by private industry to provide protection for public resources (e.g. wild fish) becomes economically unsustainable is necessary before any government creates regulations requiring coordinated disease control actions. The issue is rarely clear cut since the probability of negative effects by endemic disease transmission to wild fish populations, even when accepted as present, are rarely quantifiable. Therefore, if salmon farming is to be economically viable, the protection of the public resource cannot be driven by the need to have zero risk of disease transmission for many cases of endemic disease.

In the absence of a regulatory approach, we are left to assume that a favorable cost/ benefits to the farmer will be required to motivate and sustain cooperation between farms.

The footprint of the salmon-farming system extends well-beyond a shared body of water. Salmon farming is a globalized industry with food products being shipped worldwide. Health managers must, therefore, be aware of the implications of their decisions on food safety for consumers and must meet the requirements of trading partners for food importation. Ensuring fish or fish products are free from specific diseases, drugs or chemicals is a critical part of this food production system and is the subject of significant local, national and international regulation.

Although practices at a farm-level have started to embrace a systems-approach to population health management, expanding this model to stakeholders beyond the border of the immediate environment of the farm has been faced with challenges. Some private farm operations have questioned the scope of their responsibilities for environmental and social impacts. In the Canadian setting, for example, some industry proponents have suggested that salmon farming bears a higher responsibility that many other coastal activities as well as many other land-based farming systems. Industry critics suggest such a higher burden would be entirely reasonable based on the fact that salmon farming diseases in marine settings have a likelihood of impinging on common resources. The validity of either of these claims has not been evaluated from a systems-based approach and thus we cannot comment on their accuracy.

Ecosystem health has been proposed as a conceptual means of combining biophysical and socioeconomic considerations into environmental and health management decisions for a variety of food, natural resource and wildlife sectors and including salmon farming. Fisheries and Oceans Canada has, for example, the concept of ecosystem health management embedded in its Oceans Act and thus this concept serves as a principle for federal management of salmon farming. The ecosystem health approach is both a socially and a biologically informed concept that strives to sustain health values and goals while preserving ecological function. Paying attention to such interactions is nothing new in investigating and managing health. No program intent on managing a population health can do so without considering external environmental determinants. However, just as the concept of sustainable salmon farming is context-rich and difficult to define, ecosystem health remains a challenging concept to move from the “idea” phase to a measurable management system. Regulations or Acts based on this concept are finding it challenging to translate the concept into measurable and manageable outputs.

Regardless of the challenges and debates, both proponents and opponents of the industry advocate for sustainable salmon farming systems that protect environmental integrity and social values. However, there are several obstacles to bring this shared vision to life. Disease regulations, responsible authorities and monitoring efforts are typically segregated rather than integrated, thus preventing a comprehensive approach to managing fish health to achieve goals for sustainability. The existing research base and social consensus on the criteria that should be used to track health outcomes for sustainability purposes is currently inadequate for identifying objective management targets that will lead to sustainable farming. Rather, we tend to focus on indices of adverse effects, an approach that results in a reactive rather than proactive management regime. Historically, the regulatory and management paradigm for salmon farming has been focused on diseases and pathogens as opposed to embracing a more inclusive health promotion model that includes biotic, abiotic and social determinants of health. A transparent and inclusive participatory process that effectively links expert views with community and industry concerns should serve as the foundation for the next generation of health management regulations for salmon farming, but it is currently not a typical approach. These deficits make ecosystem-based fish health management hard to define in a meaningful and measurable way.

5.4.1 Disease modeling and empirical data

There are many ways to model diseases. Models are simplified representations of some aspect(s) of a natural system. They can be mathematical models, maps, drawing and other forms to represent what we know of the relations between a health outcome and various predictor variables. Regardless of the type of model its validity is critically dependent on the reliability, completeness and accuracy of the data on which its construction is based. Throughout this report, but especially in Chapter 4 (surveillance) we have taken the time to highlight the many challenges in meeting these data requirements for model construction. Debates around sea lice models re-enforces the problems that arise when there are deficiencies in the data available for model construction (see the corresponding section of the sea lice report for details). Because of the all of the problems in sampling wild and farmed fish, the deficits in epidemiological and ecological data for models and lack of understanding of fish disease systems, fish disease models will be fraught with assumptions and simplifications. It is extremely important that any model interpretation makes explicit reference to the assumptions and simplifications of the model. In all cases, but especially when models are heavily reliant on assumptions, sensitivity analyses that consider how changes in assumption affect model predictions must be carried out before models are used (Taylor. 2007).

Disease models have been constructed for some economically important farmed salmon diseases (e.g. IPN models by Murray, 2006), but rarely for wild salmon diseases or those diseases with important interactions (with sea lice as the obvious exception). Sea lice dynamics likely has the greatest attention for disease models of any fish pathogen (or parasite) and a detailed description of the complexity of reliable and valid transmission models is presented in the Sea Lice Report. Although disease models are useful and should continue to be developed, there are some fundamental differences when applying established methods to the marine situation. McCallum et al (2004) provides a useful synopsis of the differences between epidemiological models applied to marine environments and those applied to terrestrial:

"However, there are major qualitative differences between marine and terrestrial environments, which might have substantial implications for the application of epidemic theory to marine environments. These include:

- Higher taxonomic diversity in marine environments compared with terrestrial ones, both of hosts and parasites;
- Differences in life histories between marine and terrestrial organisms;
- The more open nature of recruitment in marine environments compared with terrestrial ones;
- Differences between terrestrial and marine environments in the modes of parasite transmission;
- Differences in human impacts on marine and terrestrial ecosystems; and
- Differences in potential means of control of infectious diseases in marine and terrestrial environments." (McCallum et al, 2004, p. 586)

It is never correct to view models as reproductions of reality. Experience with the use of models in terrestrial systems have lead to the conclusion that decisions maker must not rely on models to provide management decisions, but instead use them as part of a broader decision making process (Taylor, 2003). Models are better used in a management setting to explore options and provide hypothesis for control disease decision making. Researchers developing predictive models in terrestrial agriculture have concluded that mathematical models are better used retrospectively and their use during an outbreak to inform policy should be adopted only with great caution (Taylor, 2003; Garner et al, 2007). Models have however gained increase prominence as tools that can contribute to identifying and evaluating possible alternatives for disease control. Unfortunately, even in agriculture and public health, reliable and valid examples are often lacking, especially for diseases that are new or poorly studied. Such is often the case for many salmon diseases.

5.4.2 Minimizing the impacts of disease requires collaboration

Aquaculture has in recent years done a good job developing teams within companies that can look at health from a farm-level perspective as well as managing their industry from a food safety system prospective that is protective of consumers and trade. Many companies have in place HACCP[3] systems which serve to protect consumers. Governments have also seen the value of an approach to disease management that considers impacts beyond the farm edge. For example, the fish management regulations and guidelines of the province of British Columbia were developed with the intent of not only preventing and managing diseases on farms but also to reduce the risk of spread of disease between farms and between farms and wildlife. However, there has been less success in engaging communities and other stakeholders in developing plans to manage health risks to animals, people and habitats outside the border of their netpens. In Canada, governments struggle with effective ways to bring together industry and non-industry stakeholders to develop management plans based on ecological units (such as a bay or inlet). One reason for this is the highly politicized nature of the aquaculture debate that has entrenched the positions of various players, thus complicating constructive dialogue. This is changing, but often on a case-by-case basis where specific companies speak to specific stakeholders. The British Columbia provincial government has recently created an office of aquaculture and community engagement charged with developing effective means to bring communities into aquaculture planning. There is also significant attention in academia and government in that province in applying ecosystem-based management to salmon farming with sea lice serving as an important case study.

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[3] HACCP – Hazard Analysis Critical Control Point – a system used for avoiding food-associated hazards to consumers by managing a farm from production to distribution.

Important challenges to effectively applying a systems-based and participatory approach to fish health management include; (i) shifting regulatory perspectives on integration of responsibilities across ministries; (ii) developing effective ways to measure and weigh competing interests and values and (iii) developing evidence-based policy in the face of significant ecological uncertainties. Despite these challenges, initiatives in British Columbia represent an important step forward in systems-based management of salmon farming.

The skills, knowledge and attitudes that are required to objectively evaluate the effects of salmon farming on its surrounding environment and the development of socially acceptable and feasible management strategies requires a team-based approach that is greater than currently exists in most jurisdictions. It is generally recognized that comprehensive health management can no longer consider adverse (or desirable) outcomes in isolation. Thinking about bacterial kidney disease, for example, without considering fish nutrition, husbandry and genetics was an important reason for the slow gains that were made on controlling this disease. As society expects food production systems to be sustainable, it is clear that aquaculture cannot incorporate health management systems that only exist within the physical borders of individual farms. Until regulatory, research and industry players develop a more integrated and systems-based approach, we anticipate that many of the debates around the effects of health concerns from salmon farms will remain unsatisfactorily resolved and will be more informed by socio-economic than biologic and ecologic information. For this reason, there must be an increased focus on the human dimensions of risk assessment and risk perception; new approaches to risk assessment that deal better with weighing and balancing values; enhanced methods for dealing with scientific uncertainty; and improved participatory methods when undertaking risk assessment and management.

Chapter 6: Addressing Unknowns in Disease Risk Management

6.1 Framework for assessing risks

6.1.1 Problem statement

The first step of effective environmental planning and decision making is to establish goals, which provide a framework for related environmental impacts assessments. Unfortunately, there is substantial debate when it comes to environmental goals as they relate to salmon farming and disease. Stephen et al (2009) reviewed actual visions of "sustainability", a commonly articulated environmental goal, as they relate to fish health regulations in British Columbia and found little consensus on what the term means. Stephen et al (2009) also observed that local variation in objectives, capacities and ecologies further complicated the establishment of shared goals among and between farms. In the absence of such shared goals, attempts at formulating a problem statement that is applicable across all salmon farming will result in identifying generic rather than specific goals, objectives or targets for management.

Assessment of environmental change pre-supposes knowledge about the current state. As seen throughout this report, there are significant deficiencies in our understanding of the epidemiology and diagnosis of disease in wild fishes, about the frequency, magnitude and significance of movement of pathogens between wild and farmed fish, and about the effectiveness of various interventions to prevent or mitigate disease-associated environmental risks. The challenge facing anyone wishing to establish the impacts of salmon diseases is to disaggregate the impacts of pathogens and parasites on valued ecological components from the many other stressors facing marine biota. This challenge is even greater given the large number of unknowns regarding the ecology of many marine species in general and more specifically on the effects of disease on the fitness, abundance and distribution of marine wildlife. Even in the absence of fish farms, we lack the knowledge to forecast the health of wild fish or other species and have little data with which to understand the cyclical or random components of marine diseases in salmon farming areas. We, therefore, advocate that this document be part of an adaptive process that is reviewed and updated as new information is uncovered. Exploring methods for uncertainty analysis, qualitative risk assessment and multi-criterion risk analysis capable of combining quantitative data and social values may be a way forward to allow for more rigorous and objective assessments of the impacts of fish diseases until critical scientific uncertainties are resolved.

The problem statement for this report in this sense remains open. We have attempted to provide an interpreted overview of the state of knowledge of salmon diseases and their management in the hope of informing subsequent decisions on the selection of, and adherence to, specific standards of performance for fish health management.

A comprehensive review comparing across salmon producing areas the frequency of occurrence, impacts on farm productivity, mechanisms for transmission, and likelihood of spread to wild fish, would be beneficial for future considerations. However, this information is difficult to obtain from many areas because it exists in different, poorly accessible record formats, and thus was beyond the scope of this report. A detailed comparison of approaches to control of a single disease agent that is shared over multiple jurisdictions, such as ISA virus, was contemplated during the early draft stages of this report. However, when the authors attempted to collect this information, it was clear that the different sources of data would produce an incomplete summary despite considerable effort suggesting that it warranted a separate project outside the purview of this report.

6.1.2 Assumptions

We assumed that the principal source of risks were marine netpens. Very little time was spent on risks associated with land-based operations. We anticipate that new conditions associated with land-based marine grow-out will create new disease issues, but we have not explored them here because of the lack of experience and, therefore, data or opinion on land-based salmon farming. We further assumed that the primary way salmon farm-related diseases could decrease sustainability is by increasing the probability of wild marine life being exposed to pathogens and parasites. Risks from drug and chemical use were reviewed in another technical working group report commissioned by the Salmon Aquaculture Dialogue Steering Committee (Burridge et al 2008 available at http://www.worldwildlife.org/what/globalmarkets/aquaculture/WWFBinaryitem8842.pdf). The assumption that reducing exposure to new pathogens is a primary means of risk reduction underlies much of the legislation and farm procedures related to disease management.

We assumed that future efforts to modify fish health practices for the purpose of environmental protection will have wild species as the primary focus, but concluded that efforts to understand disease transmission factors and improving methods for optimal health management in farmed fish will provide substantial protective effects for wildlife. We therefore advocate collaborative work that generates dual benefits for farmed and wild fish, assuming future regulations and procedures allow the ongoing operation of marine salmon farming.

We assumed that statutory standards in some way reflect the values of a jurisdiction. To be acceptable and thus implementable, standard setting must take into account how jurisdictions place value on specific environmental, economic and social features. Future work at setting standards will, thus, be inherently political. The information uncovered in this report did not systematically review the legislative aspect of fish health management. Where possible, we have presented some practices that we think have application across salmon farming regions, but we have not undertaken a rigorous statutory review or inventory of all international corporate practices to ensure any practice we highlight does not contradict existing laws and regulations across regions. The task of describing all approaches to regulating disease and promoting best practices for health management across many different jurisdictions is beyond the scope of this report. It was evident that tremendous effort has been applied to the regulation of salmon farming within each jurisdiction both by governments and industry, but there is duplication of effort due to lack of coordination across jurisdictions. This is not unique to disease or to aquaculture. It is particularly evident in the area of salmon disease because of the recent and rapid development of salmon farming over the past 30-40 years. It can be anticipated that due to different institutional contexts for decision making and competing domestic interests, setting universally applicable standards for specific fish health practices at an international level will be an elusive goal. Standards may be more effective if targeted at the producer or company level.

6.1.3 Fundamental components of risk reduction

If the primary driver of risk (real or perceived) is increased or unacceptable exposure of wild marine biota to pathogens and parasites of farmed fish, then the fundamental target for risk reduction is to interrupt, reduce, or prevent the transmission of pathogens/parasites between farmed and wild fish. The strategies to achieve this that were presented throughout this report fall into three main classes of action:

- i. Reducing the likelihood that farmed fish are infected and infectious
    - a. Strategies include efforts to promote: general immune protection (nutrition, probiotics and immunostimulants, stock selection, stress reduction), specific immunity to diseases (vaccination), hatchery management and stock selection, prophylactic and metaphylactic use of antibiotics and antiparasitic drugs, and veterinary services that result in prompt, accurate diagnosis and treatment of clinically sick fish.
- ii. Reducing the environmental burden of pathogens
    - a. Strategies include waste management, dead fish disposal, hygiene and disinfection, appropriate use of drugs and chemicals, policies and procedures regarding movement of fish, and policies for fish slaughter.
- iii. Reducing the likelihood that infectious farmed fish and wild fish interact in a manner that allows transmission of infectious agents
    - a. Strategies include year class separation, fallowing, escape management, siting of netpen farms, and physical barriers, including net type and maintenance.

Taken together, these strategies represent a comprehensive infection control program that is consistent with (and in some instances exceeding) what one might see in other forms of animal agriculture. Many of these strategies have been shown in the literature, and from industry experience, to be effective at reducing the burden of infection present on salmon farms. What have not been well established are the combinations, types and details of these strategies that result in acceptable levels of risk reduction to wild marine life. We have shown above how the answer to this question will need to be pathogen-specific due to the differences in ecology, transmission and epidemiology of different disease-causing agents. We also have presented arguments and evidence that the details of disease control strategies will need to be specifically location-based according to the conservation status of local marine species populations, specific differences in vulnerability of wild species to a pathogen, local oceanographic and ecological factors, differences in species reared and differences in existing legislative tools for disease control. Despite the aforementioned issues, we found common and accepted principles of infection control that are, and can be, applied across salmon farming sectors to reduce the burden of disease on farm and the probability of transmission of pathogens and parasites to wild species.

6.1.4 Comprehensive infection control as a precautionary approach

Despite all the uncertainties plaguing our abilities to predict the effects of disease in wild marine systems and the impacts of salmon farming activities on these effects, we found that industry in the majority of jurisdictions has adopted multiple methods and approaches to infection control. Infection prevention and control are common objectives throughout the industry. The main motivation for this has been the need to control infectious diseases which were/are significantly impacting farm profitability.

The continuing struggle lies in determining exactly how much must be done to achieve acceptably low transmission probabilities and thereby avoid negatively impacting wild fish. This is in part due to the lack of consensus on what this probability should be and also to the lack of research on the relationship between specific practices and environmental risk reduction. It is reasonable to conclude that advocacy of a zero transmission probability is also advocacy for an end to open netpen farming or to any other forms of farming that uses water from marine fish-bearing waters. It also is reasonable to conclude that a non-zero probability of transmission cannot be taken to imply that an ecologically harmful or unacceptable risk exists. However, as farm population size increases, the number of potential hosts may increase dramatically for a given area resulting in increased potential for overall impact when the total parasite (or other pathogen) population is considered.

Risk is a combination of the probability of an adverse outcome and the importance of the consequences of that outcome. Acquisition of an infectious agent (an infection) does not necessarily result in disease in individuals and disease in individuals does not necessarily translate into population effects. The many uncertainties about population aspects of fish diseases prevent specification of a level of pathogen that will result in a risk except in a general or broad way. Moreover, the relationship between infection, disease and population effect is not static and will change over time (seasons, years, relative farm size, oceanic cycles etc.), locations and species. Management efforts to reduce risk must therefore be principle-based and adaptive in nature rather than specific and rigid in their application. This is perhaps most readily seen in the present Norwegian legislative requirements placed upon farmers in relation to sea lice control. During the period December-June inclusive (November-June in northern Norway) the average number of sea lice per fish shall not exceed 0.5 adult females or 5 mobile stages. From July-November (July-October in northern Norway) these levels are relaxed to 2 adult females or 10 mobile stages per fish. If sea lice levels exceed these limits then the farmer is required to de-louse. Whilst these industry-wide regulatory limits in Norway have to be seen as a positive contribution to controlling potential sea lice impacts of farmed fish, it has also to be acknowledged that these levels apply to farms of all sizes. The absolute infestation pressure (number of sea lice larvae produced per unit time) in a locality is a function of average infestation intensity and the numbers of farmed fish at a given site or fjord. It may well be that these regulatory trigger levels for sea lice will have to be adapted in relation to local changes in the size or numbers of farms in given fjord systems. We believe, however, that advocating for mandatory comprehensive infection control is reasonable, implementable and likely to result in risk reduction.

Furthermore, we believe that selecting, managing and enforcing infection-specific control practices will require research to identify meaningful and reliable indices of effectiveness. Reliable measurement and reporting of indices of effectiveness are essential to move from generic principles to locally relevant standards. Research is required if we wish to identify practices that provide the highest level of protection to wild and farmed fish.

6.2 Infection Control Summary

6.2.1a. Components of infection control in place

6.2.1b. Strengths

Salmon farms can optimize health and productivity through basic disease prevention methods that have been enhanced by almost 30 years of increasingly sophisticated research into vaccines, strategic treatments, and identifying and managing disease risk factors. Based on first principles, health management at salmon farms is largely well understood and well practiced. The scientific knowledge regarding farm control practices continues to expand rapidly. Active research on diseases in laboratory settings is reasonably well funded in major salmon producing countries. The exception appears to be Chile where, until recently, the infrastructure and resources were not as well developed and more dependence was placed on corporate activities for basic research compared to other countries. More government resources have been injected into supporting disease monitoring and control practices since 2005.

The advent of salmon farming by the 1970's capitalized on the knowledge base built on diseases of enhancement hatchery salmon where the emphasis was on the identification and control of clinical disease and less on subclinical infection states. A strong foundation in pathology, microbiology and immunology has provided a firm and growing understanding of the mechanisms of disease at the cellular and individual fish levels. Salmon farming has shifted its original focus on biomedical control and treatment of clinical diseases using drugs and vaccines, to a broader view of disease control throughout the production cycle. Technological advances remain important and are providing for more robust and long-lived protection. For example, in the early 1990's, adjuvanted injectable vaccines improved the duration of immune response to some pathogens, a critical feature of vaccines that must protect over an entire marine production cycle of almost 2 years.

By the mid-1990's, epidemiology research began to occur in salmon farming. Risk factor studies have helped identify important environmental and husbandry factors that can be modified to prevent or control disease and promote fish health on farms. More recent research of the pathology and host response to disease has been infused with the development of molecular biological investigation tools. These disciplines do not work in isolation and interaction enables many advances that are not possible alone.

The current size of the industry in different countries has attracted more attention from vaccine and pharmaceutical companies, which in turn has brought more investment into disease control methods. More veterinarians and research scientists have applied their expertise to salmon aquaculture than any other aquatic food animal. Although major contributions have been made by scientists who do not receive financial incentive for their progress (e.g. academic and government scientists), much of the increased research investment can be directly or indirectly attributed to the potential for financial return on investment. Government spending initially increased in aquaculture-related health diagnostic services and then more recently on research. International trade has recently focused on greater reliability and surveillance requirements aimed at preventing disease introduction for aquatic species. International trade issues require countries to provide evidence to support claims of disease freedom and there are more formal approaches to disease surveillance, including in wild fish, than ever before.

On-farm biosecurity practices have been greatly enhanced following episodes of severe disease occurrence when farmers as a group are reminded that there are no shortcuts in disease prevention strategies. Unfortunately, countries and companies have been slow to adopt lessons learned elsewhere until forced to address their own serious disease outbreaks. Norway began the process early because of their disease experiences in the 1980's, whereas Eastern Canada had relatively lax attitudes to disease until the mid-1990's when the first cases of ISA occurred. Chile was slow to see the need for many of the more stringent disease control practices likely because of their forgiving environment for salmon growth and the lack of indigenous salmon stocks with which to exchange disease agents. Piscirickettsial diseases affected the economics of salmon production in Chile for many years, but the nature of the disease transmission did not provide sufficient incentive to curtail husbandry practices that violated many of the best biosecurity practices learned in other areas. Recently, ISA has changed this situation but the lesson has been learned at high cost to the industry. There is also a history in many areas when they experience success in disease control for a few years that their biosecurity practices begin to wane and the risk of new disease outbreaks increase.

The strength of biosecurity as a foundation for disease control is that it is basic and simple. Long practiced in swine and poultry farming, single generation production and fallowing between generations is the key to sound biosecurity practice. The difference between aquatic environments and terrestrial farming is the inability to establish impermeable barriers that could enhance the separation of livestock from other fish. In open cage farming, the farmed fish will always be exposed to fish in the surrounding area. The exposure can be in the form of pathogen-laden water or biological material transferred from neighboring farms or wild fish. While there may be challenges to separating wild stock and farmed fish via waterborne routes, there are many effective methods that can be used to prevent human movement of disease agents. Once an infectious disease is introduced to at least one salmon farm, there is good evidence that biosecurity breaches are often the predominant reason for transmission of disease between fish farms.

Disease surveillance capabilities on fish farms provide a major advantage to the industry. Early detection is possible through the application of highly advanced diagnostic methodologies, including many molecular techniques developed for other purposes and applied and refined for fish disease agents. Detection of extremely low levels of infection prevalence is a benefit when attempting to detect cases prior to mortalities and increased risk of transmission has occurred. However, challenges still remain in interpreting some surveillance outcomes because of lack of data on false positive and false negative rates of some tests and because of problems in interpreting the risk of newly discovered microbes that may or may not be pathogens.

Salmon farmers have the ability to observe the behavior and appearance of their fish and take regular samples for diagnostic testing. This enables early treatment and limitation of disease progression, which is not possible for wild fish diseases. Many health improvements are made through the use of optimal husbandry conditions that are manipulated in response to improving knowledge of management. Having salmon contained on a farm provides a suite of options for disease control not available for free-ranging fish, including, where economically feasible, the control of water quality, stock isolation and containment.

The scientific capabilities available to salmon health management and research to support policy decisions are exceptional. A particular strength developed over the past 10-15 years has been the ability to study the complex interactions of real world variables in production settings using field samples and advanced epidemiology methods. Salmon farming leads the advancement of many aspects of intensive aquaculture, including health research. The reasons that these superior capabilities have been developed in salmon compared to other aquaculture species relate to the high value of the product and the desire of fish farmers to reduce losses due to infectious disease. The knowledge base created would not have been possible without farms driving the research agenda, particularly in the current climate of deficient financial support for wild salmon disease investigations.

The fact that health management and disease prediction affect the profitability of salmon farming companies cannot be overlooked as a strength when considering how to improve farmed fish health. Farms have a large incentive to detect early cases of infectious disease, to identify methods to prevent infectious disease, and to develop innovative ways to reduce the effect of infectious disease.

6.2.1c. Weaknesses and Gaps

Public acceptance that salmon farming is being practiced in the most sustainable manner requires that independent third party investigations (i.e. not corporate sponsored) continue to expand and provide knowledge for overall policy decisions. There is a lack of support by government and industry, as a whole, for large-scale field research (as opposed to basic laboratory research) unless there is direct support from a commercial partner. This has two implications. First is the focus of research on diseases that affect profitability for companies as opposed to sustainability of the broader system. Corporate partners therefore set the research agenda and can limit the inquiry by health researchers by affecting which issues are supported. Second is the focus of research on “patentable” technology (including drugs and vaccines) as opposed to research on broader risk factors that are generally available. There remains a lack of understanding by policy makers and funding agencies of the need for research done at fish farms, particularly epidemiology research. Such research tends to be larger scale, requiring large numbers of farms to participate, and more costly than smaller laboratory-based studies; for example, diagnostic tests to monitor cage-level prevalence in a trial are very expensive both in terms of personnel and testing costs but the information gained is of direct applicability to farm health management and risk reduction.

Another major weakness of industries around the world is the sporadic, sometimes routine, breaches in this practice, especially year class separation and site fallowing. That the basic approach of applying such practice to areas, and not just single sites, has not been adopted around the world remains an important weakness. There are very few reasons for not doing so except that it requires long term planning and short term ‘pain’ to adjust the stocking cycles of up to 50% of the sites in an area to synchronize production.

Reliance on regulations describing disinfection protocols while allowing high risk husbandry practices to continue is a severe industry weakness. Although there are regulations in many countries describing appropriate disinfection protocols for well boats, harvest vessels, and other equipment that is shared between sites, disinfection can never be guaranteed even if the protocols are completely adopted. There are anecdotal reports that well boats can be used to transport adult harvest fish to the processing plant one day, and juveniles (smolts) to a site within the next 1-2 days, and possibly be used as a site work platform in between. The risk of transmission of local infectious disease, e.g. pancreas disease virus or infectious salmon anaemia

(ISA) virus, is almost certainly increased with this kind of approach. The reason that this is not identified by farm operators as an important high risk activity as early as it should be, is probably because there is a lag time between the biosecurity breach and the disease occurrence. Nevertheless, it is a practice that has become far too common in some areas.

It would appear that when the production environment is the most amenable to altering the production cycle, then shortcuts in biosecurity occur. When smolt placement occurs in virtually every month of the year, there is less distinction between year classes leading to progressively more mixing of stocks in the same area. If there are no infectious diseases in the populations, there is nothing to share (i.e. naïve fish remain unexposed to anything new) and nothing to cause alarm. However, as soon as an infectious disease occurs, the barrier (age separation) to its spread is not present. For example, in Chile, production patterns have thrived on highly variable fish cycles that involve lake cages, estuary sites, and full marine sites. This flexibility encouraged mixing of stocks from different sources, exposure of one year-class to another in the lake or in small bays, lack of processing plant effluent controls, well boats moving fish to slaughter, and many other weakened or absent biosecurity barriers. These practices are not new to the region, but their effect is obvious when an infectious disease such as ISA is present. Substantial changes in policies have been instituted in Chile, instigated by ISA control needs, but these are likely to take some time to yield benefit.

The exposure to wild fish to “new” (that is, geographically unprecedented) or elevated disease risks is one of the most severe weaknesses of marine net pen-culture salmon farming. The greatest challenge for any farm health manager is to detect and mitigate the effect of disease introduced by exposure to wild fish. This is especially important with respect to sea lice. Whereas the outbreak of notifiable diseases (e.g. ISA in Scotland) has typically been a sporadic occurrence in the northern hemisphere, sea lice (especially *Lepeophtheirus salmonis* under optimal environmental conditions) larvae emanating from farm net pens present a year-round infection risk to wild salmonids. Disease trends in wild fish are rarely known. As a result, salmon farms are always working in an information void for when disease risk from wild fish exposure is increased. Although strict on-farm biosecurity practices would reduce this risk, it is far more efficient and sustainable if the biosecurity measures were able to be tailored and focused during high risk periods. Knowledge of disease trends and transmission dynamics between wild fish populations and between wild and farmed populations is an important gap in knowledge in many areas of the world. It also has to be acknowledged that the same pathogen can present quite different challenges to indigenous wild populations in different parts of the globe. This is perhaps especially acute with sea lice and wild salmonids because of differing life histories, and vulnerabilities of the various species of salmonids in the Atlantic and Pacific Oceans. As discussed at length above, this is also the major source of uncertainty regarding ways to reduce the transfer of pathogens from farmed to wild fish.

Transparency of disease information on farms is an important concern for many individuals or organizations critical of salmon farming. Although it is understandable that private companies would want to protect proprietary information about negative influences on profitability, lack of transparency creates public distrust. The public expects that a third party entity has oversight and knowledge of the true health status of the farming industry and will investigate and ensure appropriate response to disease threats. Confidence in that third party system does not exist in many countries. Much of the information that is provided publicly is not of sufficient detail or quality to be usable for epidemiology studies. It is a delicate balance that requires greater commitment by all parties to improve confidence while protecting confidential company information.

Considerable amounts of health-related data are routinely collected by private farming companies but centralized databases are rare. Therefore, tracking and investigating disease is usually event-based; thus, for example, a new case will be investigated following detection but the data required to understand and manage risks are available generally through research rather than routine surveillance. A commitment to these types of on-going databases for health trends is lacking.

Lastly, salmon farming continues to evolve its production methods. These developments create new and ever-changing challenges for the adaptation of health management to new production techniques and environments. For example, heated re-circulated water hatcheries have changed the growth and smoltification patterns during the freshwater phase, which then alters the need and application of vaccines. The need to continue to develop new refinements to fish health will continue for as long as there is fish farming.

6.3. Future Trends.

Health management practices are changing constantly to meet the latest disease challenge and the adaptation of husbandry methods. Arguably, the speed of advancement of scientific knowledge regarding disease detection, disease transmission factors, including host responses, and disease control methods has never been greater or more profound than in the last decade. The changes over the next decade will likely be as rapid or more.

The scientific advances made in aquatic health are, in part, due to the advances in knowledge related to diseases in terrestrial animals and humans. However, because of the introduction of farming, there also has been a considerable change in our knowledge of aquatic disease whereby the population is observable and accessible. To date, new advances in knowledge on salmon diseases have been driven by a profit motive than by the need to support public policy. For wild migratory salmonids, the situation typically in North America and Europe is that there is no ownership of the fish as such, but individuals have the right or permission to fish for them in specific locations and at particular times of year. This is not a statement about the lack of importance of disease knowledge in wild populations but a statement about the inciting factors related to research in support of disease control.

Candidates for advances in aquaculture health management, particularly salmon aquaculture, will most likely be found in improved husbandry methods through better and more cost-efficient engineering for containment systems, through more complete barriers to detrimental environmental exposure, to genetic selection for optimal productivity, through optimizing freshwater – saltwater transfer methods, and through more careful management of handling procedures. Immediately following any changes in growing conditions, factors affecting health will have to rapidly adapt to these new conditions.

Molecular biology will contribute to the understanding of which individuals and which populations are more susceptible to disease agents. Disease detection methods will be able to identify individuals infected with fewer and fewer pathogens. Factors related to reducing, or increasing, the probability of exposure to disease agents or reduced host resistance will be identified. New methods for modifying the host responses to pathogen exposure will contribute to disease prevention.

In summary, all aspects of salmon farming and health management in salmon farming will continue to develop rapidly. The challenge for health managers is to remain committed to adapting to new production methods using rigorous field investigations to identify the optimal methods to minimize impact of disease on farmed and wild fish populations. We can only speculate how these advances will reduce environmental risks, but based on first principles we can assume that reduced prevalence and distribution of disease and infections in farmed fish will reduce the risk to wild fish. We are less optimistic about advances in understanding many of the fundamental ecological and epidemiological questions required to better assess wild-farmed fish disease interactions in the short-to-medium term if the current system and priorities for research and development funding is not changed.

6.3.1 Adaptive Management

Many aspects of salmon farming are constantly changing. As changes occur in the natural environment, including water quality or seasonal changes in marine biota and oceanographic conditions, farm health management must adapt. Production management advances, including water temperature manipulation, environmental bacterial control (through ultraviolet exposure or ozone treatment, for example), host response changes (e.g. vaccination), and developments in offshore ocean cages with massive population numbers in each cage, present new challenges for optimizing health management. All of these changes require rapid adaptation and modification of disease detection and health management practices in new environments. Industry and governments must not accept that established methods of disease detection and control are automatically reliable when new production methods are adopted. Maintaining and improving the professional health expertise with continued investment in rigorous evidential science must keep pace with changes in production methods.

Risk management involves understanding and manipulating many different aspects of husbandry, environment, and host responses to pathogens. Through manipulation of the risk factors involved, the pathogen will be less likely to lead to infection or, if infection is successful, less likely to lead to disease of the host fish. The interaction between other factors and disease agents will vary from area to area. The causal factors that combine in the presence of a disease agent to create the right conditions for clinical expression of disease will have different components depending on location or jurisdiction. For this reason, local expertise in the discipline of health investigations is a very important capacity to maintain. Although reference laboratories are useful to determine if the suspected agent reacts to diagnostic tests developed and applied to the situation in the initial country, pathogen identification is only one aspect of the disease investigation and response. Immediate management or contingency plans, adaptable to various pathogen scenarios including unidentified transmissible agents, should be developed and known within the industry prior to the emergence of a disease problem.

In many situations, suboptimal environmental or husbandry conditions and relaxed biosecurity protocols will produce fish populations that are susceptible to a number of disease agents. Eliminating a disease agent from an area does not necessarily reduce the probability that another infectious agent will cause mortalities. Poor quality fish are more susceptible to infectious disease and while they may die from whichever pathogen is in the area, the ultimate cause of mortality was their poor underlying health status.

Industry and governments must recognize how changes and developments in environments, farming and diagnostic tests necessitate flexible and progressive surveillance methods. As new sampling schemes and new testing methods are developed, they should be rigorously assessed and then incorporated into the surveillance methods as soon as possible. This also holds true for vaccines and antibiotics/antiparasiticides. New developments will aid disease control in farmed fish, but some control measures will turn out to be worthless, resulting in many years of misdirected management methods. A strong program of intensive clinical trials and continuing education and knowledge transfer must, therefore, be part of any ongoing aquaculture plan.

Management must not only be focused on the “next new thing.” Trend information on endemic diseases in specific areas should continue to be tracked and managed. Governments should expand resources for collecting disease data and to make detailed disease pattern information available to farms as well as providing summaries of these to the general public.

6.4 Critical Unknowns

Throughout the report, we have identified several areas of uncertainty that affect the reliability of existing data, opinions and extrapolations and present an on-going challenge to setting fish health standards. These can be broadly categorized into:

Conceptual uncertainties

- Lack of foundational knowledge on the ecology and epidemiology of fish disease and transmission dynamics of pathogens between wild species and farmed salmon, and often even between farmed salmon cages and sites, leading to ignorance of the necessary and sufficient suite of variables and relationships that must be considered in risk assessments

Scientific uncertainties

- Lack of research or analytical tools to reliably measure disease impacts on wild species populations
- Deficits in data on prevalence, distribution, and effects of wild fish disease and limits in long term epidemiological information on patterns of salmon farm disease
- Lack of capacity to forecast changes of risk, especially in response to predicted climate change or changes related to farm production methods
- Ambiguity arising from different value judgments of existing scientific data

Technical uncertainties

- Lack of critical assessment of the protective effects of fish health management strategies from an environmental protection perspective and/or from the perspective of farm productivity
- Lack of information on how new technologies may affect disease dynamics and their associated risks

Social uncertainties

- Lack of clarity or consensus on the goals and indicators of fish health and its influence on sustainability

- Lack of assessment of information on the economic and social features of management interventions that would be acceptable to stakeholders and could be feasibly implemented

Regulatory uncertainties

- Lack of a comprehensive review of regulatory standards, their implementation and their effectiveness

The presence of uncertainty is not unique to salmon farms and disease, but often plagues environmental impact assessments. One of the purposes of this report was to make many key uncertainties explicit, and their implications apparent, so they could be taken into account when developing standards for fish health. Our discussions of uncertainty cannot be taken as support for the claim of a lack of sound science to prove the presence (or absence) of a risk. Rather, it is presented to help refine the manner in which risks should be considered. We suggest that salmon farm disease hazards do not have sufficient certainty about their probability and magnitude to allow for classic risk assessment or sensitivity analysis to be applied. Rather, techniques such as scenario analysis and wider engagement, consultation and deliberation are likely better suited approaches given the current level and nature of uncertainties.

One option for dealing with uncertainty is to invoke wide safety margins, sometimes referred to as applying the precautionary principle. Specifically with regard to sea lice, for example, a strongly precautionary approach has been recommended industry-wide in the sea lice report, given the quantitative uncertainty surrounding many aspects of wild-farm interactions in differing parts of the northern and southern hemispheres. These approaches have been subject to significant debate and conflicting interpretations and thus are easier to invoke in principle than to apply. For example, a UK governmental plan suggested that precautionary approaches should not be applied unless decisions cannot be made due to prevailing uncertainties (see http://www.parliament.uk/documents/upload/POSTpn220.pdf). Given that many governments and industries have made their own fish health management decisions, it is unclear if this criterion applies. The lack of evaluation of the effectiveness of existing policies for controlling fish disease risk further complicates decisions as to how to apply the precautionary principle. Regardless of how this political debate about the application of a precautionary approach might end, we see a need for ongoing research and monitoring and transparent and consultative consideration of various options for management.

6.5 Priorities

6.5.1 Next Steps to Indicators

Indicators should provide key information on the function, structure and composition of the system of interest. Adapting the science of fish health and ecological indicators to develop a suite of indicators that can be used for the management or certification for salmon farms is complicated by a number of factors (adapted from Dale and Beyeler, 2001). First, most studies have examined only a few of the candidate indicators for what are undeniably complex systems. Second, there has been a poor linking of indicator selection and management goals. Third, there has been no organized or systematic attempt to develop salmon farm health indicators, especially for those that reflect risk of transmission of diseases to wild fishes.

It is clear that a few indices will fail to adequately characterize the wild fish-farmed fish disease system. Selecting a suite of indices that is meaningful both ecologically and epidemiologically - as well as understandable by consumers, the public and policy makers - is a challenge facing many facets of environmental monitoring, not just salmon farming. More rapid progress may be made towards developing opinion-based best management practices that are reviewed and updated on a regular basis as new knowledge emerges.

This report compiles information about the state of knowledge for salmon diseases and, in so doing, is an attempt to help identify the gaps in knowledge. These gaps should be addressed and re-evaluated through the collection of evidence to support or revise policies as the various standards are developed and implemented. The following is a list of priorities for developing the information needed to shift from opinion-based selection to evidence-base selection of indicators of appropriate fish health practices:

Risk factor studies within zones

> Epidemiology studies can detect some basic factors that apply to many different areas and production methods. However, the details of production methods vary considerably around the world, causing some factors to dominate in one area yet be

absent in other areas. For example, well boats are used extensively in Norway, Scotland, and Chile, but not at all in Eastern Canada. The proximity of culture sites, to one another or to processing plants, can be a critical factor in some areas such as Region X in Chile, but of negligible importance in Region XII. Over time, these factors change because of differences in farm management, the changing host-pathogen relationship (e.g. a vaccine is introduced), or in our ability to detect infections. For this reason, epidemiology studies need to be repeated to evaluate current disease dynamics between farmed fish sites. In addition, risk factor studies directed explicitly at farmed-wild fish interactions should be a priority for agencies interested in making evidence-based risk management decisions.

On-going monitoring, database compilation and third party analysis

Epidemiology studies investigate the real world interactions between disease and hosts in their natural environment. To accommodate changes in any of these aspects of the relationship over time, repeated studies would truly benefit from better centralized database developments, at least for outcomes related to mortalities and basic characteristics. Many areas of the world have initiated such centralized production and health monitoring tools, including British Columbia in the 1990's and Chile today. Although very useful to describe general patterns, none of these systems developed sufficient detail to accommodate most epidemiology studies.

Centralized databases require constant attention and commitment to maintaining their validity and usefulness. However, the concept of having a third party with oversight of trend data is essential to public trust that disease information is not being hidden. The industry and governments involved in salmon aquaculture must come to grips with the simultaneous need for confidentiality about company and site specifics and the need for disclosure of disease information (suspected and confirmed). In most instances, the line between monitoring disease trends and release of company confidential information is too vague. Enforcement of regulated disease control at individual sites is often put into this mix as well. The result is that trend information is lost when the actual use of the information is suspect.

The home for third party databases should not be in government and there needs to be specific guidelines as to what remains confidential and what is used to generate summaries. Investment in a participatory process that engages and respects multiple stakeholders will be required to ensure cooperation and confidence in such a system. Issues of who bears the cost of this system and its equity with other food-producing sectors will need to be confronted. Once these details are acceptable to all parties, regulations could induce broad and inclusive producer participation ensuring the inclusion of information and practices most influential on the trends.

Creation of a funding mechanism to address public and corporate research and monitoring needs

The current research funding environment in most countries is based either on basic laboratory science or promoting commercialization of a product or service. Most of the risk management studies that have been discussed in this report involve either products from vaccine/drug companies to prevent or control disease or they involve multiple farm sites for data collection. In most cases of risk management studies, the funding will be forthcoming only if farms agree to the large financial investment required to match government funding programs. However, in most cases, the objectives are to provide results that will benefit public policy or industry-wide management. Industry partners may be challenged to convince investors to support research that does not provide return on investment or provides competing companies with new advantages. When not all farms must participate, individual companies can avoid the cost but share in the benefit. More and more pressure is put on the researchers to provide more (sometimes all) benefit to the investors, but this means that industry-wide advances in health management are impeded. In the worst situations, companies view the results as being controllable by their interests and can delay or veto the actual study or the public disclosure of results. If public policy makers wish to resolve or reduce many of the uncertainties that challenge wild-farmed fish health risk management then, novel ways for research funding partnerships must be developed. Governments must recognize the difference between funding commercial research for a single company’s benefit against its competitors and health research that must be shared between companies to maximize the benefit to farming and to wild fish and to stakeholders independent of the aquaculture industry.

Monitor trends for endemic disease on the farm with the intent to decrease mortalities first and then decrease the prevalence of infection

Many of the disease surveillance programs of countries are designed to meet the needs of international reporting for trade purposes. As a result, many important endemic diseases are not included in government programs. Once a disease is endemic, then its presence in the region is assumed and there is little perceived need to commit, at the government level, to the continued cost of disease testing. However, that approach ignores the need to understand the disease/infection trends that will affect transmission potential within and between farms and between farmed and wild fish. This is an ongoing commitment that is defaulted to industry and which then causes difficulty in maintaining compliance by all farmers, especially the farms that do not value rigorous health management practices (sporadic data collection will mask many trends). When government does not cover the costs, but instead regulates farms to comply, under-reporting of disease occurrence can arise.

Quantification of biosecurity breaches

There is a difference in detecting breaches in biosecurity practices that then require remedial action, including penalties to farms, and the actual monitoring of success of biosecurity practices. Reliable information regarding the proportion of sites performing appropriate biosecurity provides public confidence that a known proportion of farms practice defined minimum standards. However, the current methods of assessing biosecurity breaches are connected to enforcement and this leads to an overly optimistic appraisal. It is expected that any instance of evaluation will lead to short-term improvements in adherence to protocols but this may not reflect common practice. Detaching the enforcement and monitoring is a necessary step in having reliable quantification of biosecurity success and failure.

Biosecurity measures: observations and measurable pathogen concentrations

The standards that are developed for biosecurity need to have methods for reliable and repeatable measures of successful practices. For example, recording the color code of disinfectant at multiple points during use whereby there is a known elimination success against selected pathogens; of quantifying the concentration of a non-pathogenic marker bacteria in processing plant effluent could be a measure of successful decontamination of effluent; and so on. The end goal is to objectively measure ongoing practices rather than selectively observe behaviors.

Biosecurity that involves disinfection of equipment is always less desirable than avoiding the multiple use of such equipment, particularly when such use crosses natural transmission barriers like separated age classes over multiple sites or production areas. Disinfection protocols can be audited but never guaranteed to completely remove potential for disease transmission. For this reason, the occurrence of production practices in which disinfection is critical to risk mitigation, such as the use of the same well-boats for smolt (juveniles) delivery and harvest (adults), should also be quantified. When possible, industry must work to eliminate such occurrences.

Surveillance of wild fish (e.g. non-lethal samples)

Adequate surveillance for diseases in wild fish is lacking in many salmon farming areas of the world, as are non-lethal methodologies to sample wild salmonids (often from critically endangered populations). Understanding the infection patterns and dynamics as they change through time, with location and among host species, are critical information gaps that affect decisions of immediate relevance to the farm (for disease prevention strategies) and regarding the level of acceptable risk for disease transmission from the farm to the wild. Understandably, disease surveillance in wild species is very problematic and requires a large commitment of resources; however considerable research effort also is required in the development, optimization and evaluation of non-lethal testing for fish pathogens. Nevertheless, the importance of disease transmission dynamics to wild populations and to the interaction between wild and farmed salmon requires a concerted, international approach to more intensive wild fish disease surveillance and fundamental research.

Developing new methods to quantify the impacts of farmed salmon disease on wild fish

There is a large deficiency in not being able to sample and test representative individuals from wild populations. New methods for measuring rather than modeling or estimating the effects of shared diseases are critical. For example, a partial solution may be establishing small sentinel populations that can be used for testing of exposure close to and far from farms. Although many concerns will arise as to how these sentinel fish reflect the true state in the wild, they do add to the knowledge base in many situations. In some countries there also are national legislative responsibilities of researchers to ensure and maintain the health and welfare of experimental fish, including those deployed in the natural environment. This is not easily achieved unless sentinel cages are inspected regularly and thoroughly. The cost of establishing and maintaining these small sentinel populations will be high. However, the benefits need to be seriously considered. International collaboration on establishing such sentinel populations may also be part of generating greater advances in wild fish disease surveillance. The true reflection of disease risk assessment and management requires more emphasis on investigations of populations and the dynamic of interactions between biological and human communities. Risk factors cannot be investigated in isolation but must be assessed in the natural settings with all of the potential interactions involved. Without methods to measure the effects of management changes on risk to wild fish, regulators or industry will be unable to reliably identify risk reducing practices or indices of risk.

International collaboration and cooperation on disease surveillance

There is a great deal of effort expended by researchers and government scientists from around the world to share information at conferences and training sessions. Although this has benefit for the advancement of science, an under-emphasized component of this interaction is the lack of funding opportunities that are shared across national boundaries. Many salmon farming companies operate sites in many different countries so their investment crosses international boundaries but their investment in company research resources is usually concentrated in one location. Governments, charities, and research councils tend to fund research studies done by their own scientists in their own countries. However, in Europe, the European

Commission provides a notable exception to this generalization. Europe now has a long history of often large-scale, ambitious research partnerships funded within the various programs and frameworks sponsored by EU funds. Not only is international collaboration encouraged, it is a basic requirement of many research proposals. Moreover, there invariably are minimum requirements for national scientists and research institutes to include small to medium sized enterprises (SMEs), and even large commercial partners, in the research. Finally, even scientists from non-member states of the European Union can be included in research projects. Norway, for example, is not an EU member, but as an "associated state" Norwegian scientists and institutes are enabled and encouraged to participate in specific research programs. Funding of joint research with North and South American countries requires further development.

Notwithstanding the foregoing, conflict can arise when a disease transmission issue exists in one location but companies wish to invest in science at their home base, leading to a perceived deficit of local knowledge of the disease issue. Both corporations and governments must move to more co-operative ventures (perhaps along the EU model) in investigating disease dynamics across regions. Furthermore, involving scientists from other countries in disease issues has the added benefit of the transfer and sharing of experience with different disease presentations in different environments and conditions. Prevention strategies and detection capabilities can be developed in other countries prior to the arrival of new pathogens. This co-operation is essential to more effective, global management of salmon disease transmission.

6.5.3 Impact assessment tools

Much of the discussion in this report has focused on quantifying and qualifying risk of disease transmission between farms and between wild and farmed fish (both directions). Some level of transmission risk occurs in virtually all of these situations to varying extents. The challenge is to identify the magnitude of the risk for such events to occur and to differentiate activities of farming or of wild fish exposure that pose an unacceptable risk. Unacceptable risk is determined differently by various stakeholders. Nevertheless, the ability to categorize even higher from lower risk activities is often missing without quantifying the frequency of infection in natural production settings. Quantification of frequency, and factors associated with increased frequency, is a challenge that requires co-operation between government, industry, researchers, and wild salmon stakeholders. Development of improved methods to assess the impact of disease agents is a shared responsibility and will benefit both wild and farmed populations.

Environmental interactions are extremely complex and attempts to simplify the assessment of the impact of a single factor (even the single factor of farm proximity) have proven elusive. Synergy and antagonism of multiple factors that are difficult to measure and change over time periods shorter than our ability to monitor them result in huge information gaps requiring unproven assumptions in their interpretation. Outcomes in scientific papers have most often looked at risk factors in isolation, in simplified systems or by using important assumptions. Widely applying the results from such studies have led to erroneous conclusions that have failed to remedy debate or even successfully manage the disease. The lack of integration of results and studies that examine disease from a systems perspective does not promote management by industry or resolution by government for a sustainable health perspective. On the contrary, it can produce a reluctance and mistrust of science to generate any useful assessments of risk and policies that do not work in concert towards goals of sustainability.

Science can provide more refined estimates of risk or more appropriate estimates of risk for different situations, but there will always be exceptions and changes to those estimates over time and location. Science cannot identify what is good or bad about disease transmission potential and the risk to wild salmon populations. Science can provide reliable evidence of many aspects of the disease transmission probabilities and will continue to improve the methods to generate that evidence, but the end conclusions must be made by society, balancing the evidence of harm versus the evidence for less harm.

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