grocentre.is/ftp Final Project 2019

DISEASE PREVENTION AND CONTROL MEASURES IN SALMONID FARMING: BIOSECURITY MANAGEMENT FOR THE CHINESE INDUSTRY

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ABSTRACT

Atlantic salmon farming has been one of the fastest increasing food industries since the 1980s. As a new producer of Atlantic salmon farming, China's salmon farming industry has developed rapidly in the past decades but is still in the early stages of development. Biosecurity in aquaculture is a set of preventive measures, which have been proved to be effective and successful in salmon farming management. To develop practicable advice to China's salmon farming industry, a comparative analysis of the industry's current health status and management as well as biosecurity routine practices, was conducted. Questionnaires were sent to both governmental regulatory agencies and salmonid producers in China. On the governmental level, aquatic health management in China is based on the principles found in the OIE Aquatic Animal Health Code and therefore has a common framework like other Atlantic salmon farming communities, to build on. On the farm level, besides basic biosecurity knowledge level, it is of paramount interest to increase the perception and belief of biosecurity practices, thus motivating the industry towards biosecure and sustainable farming. Challenges and potential improvement points for health management and biosecurity for the Chinese Atlantic salmon industry, both on governmental and farm level, are discussed.

Keywords: Biosecurity, Salmonid farming, China

This paper should be cited as:
Ye, S. 2020. *Disease prevention and control measures in salmonid farming: biosecurity management for the Chinese industry*. UNESCO GRÓ-Fisheries Training Programme, Iceland. Final project.
http://www.grocentre.is/ftp/static/fellows/document/Shigen19prf.pdf

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LIST OF ABBREVIATIONS

AGD	Amoebic gill disease
BKD	Bacterial Kidney Disease
EHN	Epizootic haematopoietic necrosis
ERM	Enteric Red Mouth
IAVBC	International Aquatic Veterinary Biosecurity Consortium
IHN	Infectious hematopoietic necrosis
IHNV	Infectious hematopoietic necrosis virus
IPN	Infectious pancreatic necrosis
IPNV	Infectious pancreatic necrosis virus
ISA	Infectious salmon anemia
ISAV	Infectious salmon anemia virus
OIE	Office international des epizooties
PD	Pancreas Disease
RAS	Recirculating aquaculture systems
SRS	Salmonid rickettsial septicaemia
VHS	Viral Haemorrhagic Septicaemia

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1 INTRODUCTION

1.1 Background

The global fish consumption was 20.3 kg per capita in 2016, with over 50% of the volume originating from aquaculture (FAO, 2018). In 2018, aquaculture supplied 83 million tonnes destined for direct human consumption, while wild capture accounted for 73 million tonnes. It is predicted by the World Bank, by 2030, 62% of fish for human consumption will come from aquaculture (Msangi et al., 2013). With the fast-growing middle class, the consumption of high-quality proteins continues to increase. As a healthy seafood resource from the sea, Atlantic salmon (*Salmo salar*) farming has been one of the fastest-growing food industries since the 1980s. In 2018, all the salmonid supply from farming and capture productions was 3.2 million tonnes with farmed Atlantic salmon contributing 2.2 million tonnes (Mowi, 2019). The majority of the world's Atlantic salmon production comes from Norway, Chile, UK and Canada.

Diseases caused by pathogens or due to sub-optimal environmental factors is one of the most important limiting factors in Atlantic salmon farming as well as in fish farming in general. For instance, the hypoxia dead zones in the Gulf of Mexico (Smith et al., 2017) and environmental shocks in Norwegian salmon farming (Asche, Oglend, & Selland Kleppe, 2017). The most well-known and worst case is the outbreak of the infectious salmon anaemia (ISA) in Atlantic salmon farming in Chile, which caused Chile's Atlantic salmon output to decrease from 403,000 metric tons in 2008 to 130,000 metric tons in 2010 (Asche, Cojocaru, & Sikveland, 2018). Besides, other diseases also cause significant losses to the Atlantic salmon farming industry worldwide including the parasitism caused by sea lice, salmonid rickettsial septicaemia (SRS) caused by *Piscirickettsia salmonids*, and infectious pancreatic necrosis (IPN) caused by the pancreatic necrosis virus (IPNV) as well (Asche, Cojocaru, & Sikveland, 2018).

An approach to manage aquatic health with sound scientific veterinary principles was developed by the International Aquatic Veterinary Biosecurity Consortium (IAVBC), which also offers solutions that should meet the needs of producers and government regulatory agencies (Palić, Scarfe, & Walster, 2015). The approach focuses on applying several important core OIE processes that are important for developing any biosecurity plan tailored to specific epidemiological units, covering everything from a continent to a country, a defined region or area, to a single farm and beyond. Biosecurity procedures based on the approach above have been proved effective and successful in disease management in Atlantic salmon farming and other species industries.

1.2 Rationale

Though China accounts for more than half of the world's aquaculture production, most are from the production of low value species which means low value output and high resource input. Considering the limitation of resources and environment pressure, the Chinese aquaculture industry must pay more attention to profitable species such as Atlantic salmon and other high-value species. China began to introduce Atlantic salmon eggs and fry in 2010, and by 2017 total production of salmonids reached 44,549 tonnes (FAO, 2019). With the rapid development of the industry, health problems will occur simultaneously thus limiting the sustainable development of Atlantic salmon farming in China. Biosecurity is a set of effective tools to reduce the risk of catastrophic losses from infectious diseases, which have been applied successfully in many salmon farming companies. This study aims at comparison analysis of the salmon farming industry especially biosecurity measures of China and other countries, trying to develop practicable advice for China's Atlantic salmon farming industry.

2 RESEARCH OBJECTIVES

Sub-optimal health and husbandry are one of the most important limiting factors of sustainable aquaculture development. Diseases in Atlantic salmon farming and their prevention and control measures are well documented. However, Atlantic salmon farming in China is still at an early stage. Information on Atlantic salmon farming in China is limited and the farming technology level is relatively low. A detailed analysis will focus on the areas of main diseases and corresponding prevention and control measures that suggest a practicable management strategy to the Atlantic salmon farming industry in China. The study objectives are:

2.1 General objective

- Disease prevention and control measures in salmonid fish farming.

2.2 Specific objectives

- To identify the industry status of salmonid fish farming in China.
- To assess the biosecurity status of salmonid fish farming at authority and farm level in China.
- To provide practicable advice on biosecurity management measures to China's Atlantic salmon farming industry.

3 METHODOLOGY

3.1 Study design

The study areas involve the salmonid fish farming industry, its biosecurity and overall fish health management practice.

Information for the study comes from two aspects, that is, literature review and questionnaire. Firstly, by reviewing relevant published and unpublished literature from reports, journal articles, workshops and official government documents as well. Secondly, by means of a questionnaire for collecting information on current health status, biosecurity practices and mitigation measures from the Chinese Authorities as well as the salmonid farms.

3.2 Study tools

The specific tool used in this survey is a multiple choice questionnaire. Due to its infancy, official information or data on the salmon industry is limited. Questionnaires at authority level and farm level are designed to survey the authority rules and regulations and the knowledge and practice of the people working on the farm, respectively. The questionnaire at authority level was sent to government officers or biosecurity experts in universities while the farm level questionnaire was sent to salmonid farms.

Anticipated interpretation dilemmas were regarding the limited number of answers from the farming staff as well as how biased individual answers could be valued for interpretation. Qualitative method chi-squared (χ^2) test and/or Fisher exact tests were used to critically evaluate the data information received from the questionnaires.

Questionnaires at the authority level and farm level are listed in the appendix section.

3.3 Study area

The study area was the salmonid farming industry in China, which involves the salmonid fish farming industry, biosecurity and fish health management practices.

The species, location, scale and output were important factors to be taken into consideration. In addition to health management and mitigation measures with a special focus on the current status and practices in the Chinese salmonid farming. In detail, ten fish farming companies were selected for questionnaire survey, which included two Atlantic salmon farms, six rainbow trout (*Oncorhynchus mykiss*) farms, one Sharp-snouted lenok (*Brachymystax lenok*) farm and one Coho salmon (*Oncorhynchus kisutch*) farm.

4 GLOBAL SALMONID FARMING INDUSTRY

4.1 History and current status of salmonid farming

Aquaculture has been the fastest-growing food production industry in the world over the last three decades, and the annual average growth rate since 2000 is 6.1% (FAO, 2018). In 2017, the global production of salmonid fish was 3.2 million tonnes, with Atlantic salmon (2.36 million tonnes) and rainbow trout (0.82 million tonnes) as the principal species (FAO, 2019). Globally, Atlantic salmon is one of the most intensely farmed and highly valued fish in modern aquaculture (Pettersen, Osmundsen, Aunsmo, Mardones, & Rich, 2015). Atlantic salmon farming began in the 19th century in the UK in freshwater by stocking waters with parr. Modern Atlantic salmon farming began in the 1960s in Norway, and the sea cage was first used in farming to raise Atlantic salmon to marketable size (Jones, 2004). Atlantic salmon farming has been one of the fastest-increasing food industries since the 1980s, and the production increase of Atlantic salmon is more than 800% since 1990. In 2018, the production of farmed Atlantic salmon was around 2.36 million tonnes, the increase of which is about 7% from 2017 (Mowi, 2019). Even with this quick development, the total global salmonid supply still only accounted for a small part (4.4%) of the global seafood supply in 2017. According to the report from Mowi (2019), there are considerable opportunities in Atlantic salmon farming compared to other aquaculture species (Mowi, 2019). The newest information from GLOBEFISH showed that global production of farmed Atlantic salmon is expected to rise by around 6.5 % in 2019 according to the latest estimate of 2.6 million tonnes, which would be the highest year-on-year increase since 2014 (GLOBEFISH, 2019).

4.2 Salmonid production systems

Salmonid fish farming usually consists of two stages like the one that takes place naturally, where the first stage takes place in freshwater and the second in seawater (Melberg & Davidrajuh, 2009). The fish grow in land-based hatcheries with freshwater until they have reached full seawater tolerance at approximately 100 grams. Then the fish, especially Atlantic salmon is transferred into open net-pens located at sea site for the on-growing period with seawater until harvest (Beveridge & Little, 2002). At present, most production of farmed Atlantic salmon is produced in this type, *i.e.* sea-based cage farming. With the rapid development of the industry, limitations due to regulatory and environmental aspects, different infectious diseases such as Infectious Salmon Anemia (ISA) as well as increasing sea lice infestation, restrain further growth of sea-based cage farming systems. Biological sustainability now acts as a significant constraint on increased production (Hersoug, Mikkelsen, & Karlsen, 2019). In this situation, new technology has become a possible solution to overcome the "limit to growth". Advances in recirculating aquaculture systems (RAS) reduces water and energy consumption, which provide an opportunity to exercise control in terms of both the internal environment (water quality etc.) and the external environment (escapees, waste, disease parasites, etc.). Land-based farms using RAS are the chosen solution by most farms under development or planning, which are currently being developed in numerous countries including the USA, Canada, Denmark, Norway, China, Korea, and South Africa (Bjørndal & Tusvik, 2019). So far, only small farms are in operation, however, several investors have quite ambitious plans.

Rainbow trout is native to the cold-water rivers and lakes of the Pacific coasts of North America and Asia. As one of the principal salmonid species farmed, rainbow trout is farmed in the freshwater and seawater of more than eighty countries because it tolerates a wide range of conditions, both environmental and regarding production (Woynarovich, Hoitsy, & Moth-Poulsen, 2011). Rainbow trout grows in land-based hatcheries with freshwater before it is transferred to the on-growing stage. On-growing rainbow trout can live in freshwater and seawater as well, while on-growing Atlantic salmon is always in seawater. The on-growing systems for rainbow trout consist of land-based flow through systems and cage culture in freshwater and also in marine environments (Beveridge, Woo, Bruno, & Lim, 2002; Jokumsen & Svendsen, 2010).

4.3 Global producers of salmonids

The Atlantic salmon farming industry develops well in the areas that lie within latitudes 40-70º in the Northern Hemisphere, and 40-50º in the Southern Hemisphere (Mowi, 2019). Besides Norway, the major production areas in the world are: Scotland, Ireland, the Faroe Islands, Canada, the North Eastern seaboard of the USA, Chile and Australia (Tasmania) (Figure 1).

The Norwegian Atlantic salmon farming industry is the global leader and has the potential to become the country's leading ocean industry in the future (Norwegian Ministry of Trade Industry and Fisheries, 2017). Norway's total production was 1.13 million tonnes in 2018, which accounted for near half of the global Atlantic salmon production. Norwegian success reflects the excellent deep sheltered sites available, favorable hydrographic conditions (stable temperatures and salinities), natural salmon strains that mature late, and heavy governmental support and investment.

Chile has become a major producer since Atlantic salmon was introduced from Norway and Scotland in the early 1980s. Benefits from low production costs and easy access to fish meal for salmon feed production, Chile is the second-largest producing country of farmed Atlantic salmon (Asche, Cojocaru, & Sikveland, 2018). Chile's output reached 0.40 million tonnes in 2008 but plunged to 0.13 million tonnes in 2010 because of the outbreak of severe viral disease, ISA (Fischer, Guttormsen, & Smith, 2017). In 2018, Chile is globally the second largest Atlantic salmon farming country with a total production of 0.61 million tonnes (Mowi, 2019). Salmon farming in Tasmania started in 1984 with the importation of eggs from Nova Scotia, Canada. Enjoying favorable sea temperatures and relative isolation from other wild and cultured Atlantic salmon, the industry avoids some of the major infectious disease problems.

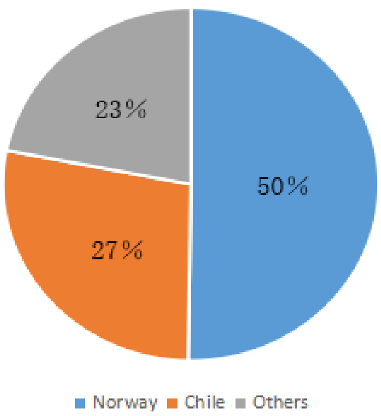

Figure 1. Atlantic salmon output (share) of Norway, Chile and other nations of the world.

At the company level, the top 5 companies of farmed Atlantic salmon are Mowi, Salmar, Lerøy Seafood, Mitsubishi/Cermaq and "New Aquachile" (Agrosuper) (Figure 2) (Mowi, 2019). The first four of these companies are of Norwegian origin. Mowi Group represents the largest total production, harvesting around one-fifth of the salmon produced in Norway, and about one-third of the total production in North America and the UK. The total production of Mowi is about 0.32 million tonnes accounting for 17.8% of the global production. "New Aquachile" (Agrosuper), the fifth-biggest Atlantic salmon producer, is the biggest Atlantic salmon farming company of Chile with the total production of 0.11 million tonnes in 2018 (Mowi, 2019).

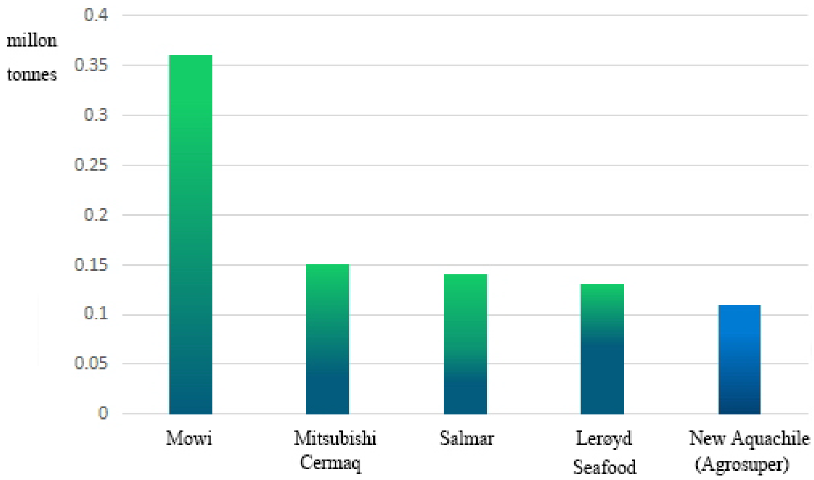

Figure 2. Top 5 global companies of farmed Atlantic salmon in 2019.

4.4 Salmonid farming industry in China

Salmon farming developed from the 1970s and has been steadily progressing in recent years. Nevertheless, the salmonid fish product data cannot be retrieved directly from China Fishery Statistical Yearbook due to the relatively small portion of the total production in China. According to the statistical data of FAO, the total production of salmonids in 2017 was 44,549 tonnes and the total production value estimated to 122.8 million dollars. Of which, the output of rainbow trout is 41,460 tonnes while the other salmonid species account for little more than 3,000 tonnes of the production (FAO, 2019). There is no statistical data on the Atlantic salmon production volume that can be retrieved from FAO. Apparently, the main salmonid fish species farmed in China is rainbow trout which accounts for more than 90% of the total salmonid production. Mostly, the Chinese rainbow trout production is with triploid fish which is being cultured in cages in large reservoirs, plateau lakes and reservoir bays. Most rainbow trout production is in Qinghai, Gansu, Liaoning and other provinces of China (Figure 3). Artificial seedling technology of triploid rainbow trout in Denmark, England, Canada, and other countries is the source of eyed eggs import to China for farming. The annual output of triploid rainbow trout is about 20,000 tonnes (Group, 2019). Besides rainbow trout, some companies have begun to farm Atlantic salmon with land-based RAS facilities in Shandong Province. In reference to the questionnaires, the annual output of Atlantic salmon is about 2,000 tonnes.

In addition, China started sea cage salmon farming by using the Yellow Sea Cold Water Mass about 130 nautical miles from the coastline of Rizhao, Liaoning province (Figure 3). The cage called "Deep Blue No. 1" is the biggest fully submersible ocean fish farming net cage for 1,500 tonnes of salmon per cage, which is as tall as an 11-story building. The technical route and basic equipment developed by Ocean University of China have been verified in 2019 (Figure 4) (Olsen, 2019). Currently, half of the 300,000 salmon in Deep Blue No. 1 is Atlantic salmon and the other half is rainbow trout (Ni, 2019). Built on the success of China’s first deep-sea fish farming facility, its sister farm "Deep Blue No. 2" is to be built, which could hold one million salmon, tripling the outage of its predecessor. In the next few years, a series of “Deep Blue” cages will be constructed to form a “deep-sea salmon farming platform” with workboats, processing vessels and transport vessels (Olsen, 2019).

There are a few rainbow trout farming companies in China. Of all Chinese rainbow trout farming companies, Qinghai Minze Longyangxia Ecological Aquaculture Co. Ltd. (QLEA) is the largest company with an output of about 13,000 tonnes per year. At present, two relatively big companies, Oriental Ocean and Wanzefeng Fisheries are the main producers of Atlantic salmon in a land-based RAS producing system in China with hundreds of tonnes of annual output. In fact, Wanzefeng Fisheries is the company that is developing Atlantic salmon farming with the fully submersible net cage Deep Blue No. 1 in the Yellow Sea (Ni, 2019).

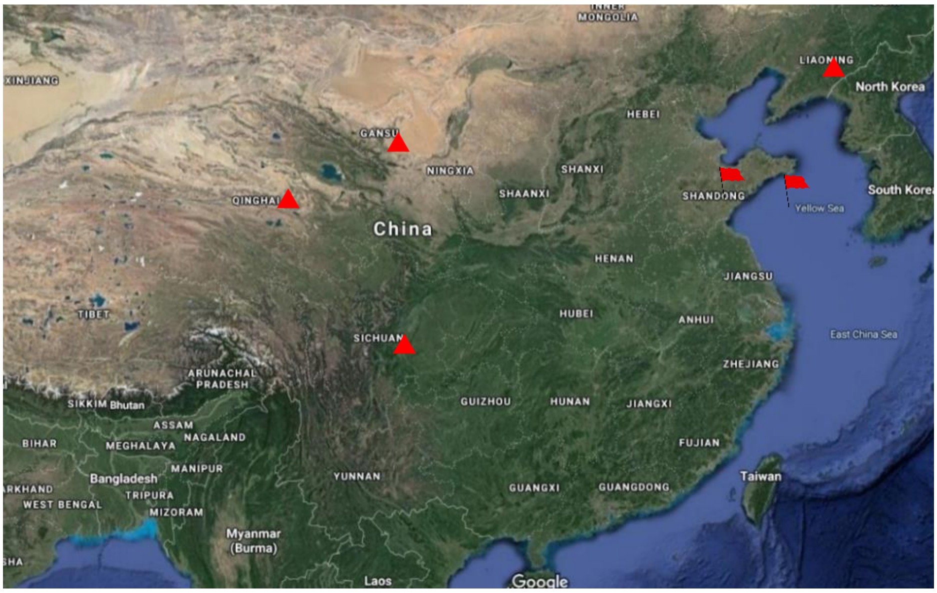

Figure 3. Distribution of main Atlantic salmon farms and rainbow trout farms in China. Note: Atlantic salmon farms (🚩), rainbow trout farms (▲).

Figure 4. "Deep Blue No. 1”. (Photo from https://salmonbusiness.com, Olsen, 2019).

5 MAIN DISEASES AND THEIR CONTROL MEASURES IN FARMED SALMONIDS

5.1 Relation between key factors in Aquaculture

A disease is an abnormal condition often associated with specific clinical symptoms and signs, which may be caused by external factors such as pathogens and/or by internal dysfunctions (Menon, 2019). In aquaculture, disease is one of the most important limitations of the sustainable development of the industry. There are many examples that aquaculture industries or companies have been on the verge of collapse with serious economic and socioeconomic consequences due to diseases. Besides the pathogen factors, sub-environmental conditions are another important factor in the occurrence and development of aquatic animal diseases. Sometimes environmental factors may play a more important role in the disease occurrence and development of aquatic animals because of its aquatic environment. In other words, the occurrence and development of aquatic animal diseases are the results of interactions between the key factors in an aquaculture environment, which include wellbeing and fitness of the fish stock, the pathogens (i.e., species, quantities, pathogenicity etc.) and all of the environmental factors (Hedrick, 1998). The complex relationship between them can be illustrated by the classic tricyclic diagram (Figure 5). It can be seen from the figure that the three factors interact with each other and are in a dynamic changing balance process. The disease occurs when the balance is broken between the body's resistance to the sub-environmental conditions and/or the pathogen's infection pressure.

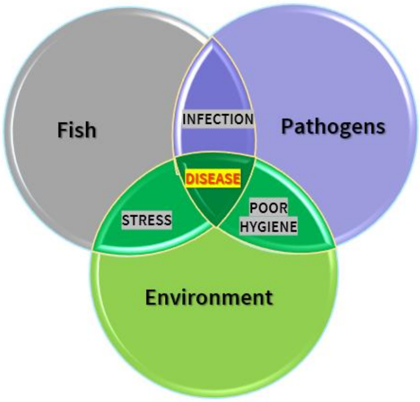

Figure 5. Complex relation between key factors in Aquaculture. Adapted from Hedrick (1998).

Pathogens are one of the most concerning factors in the occurrence of disease. There are various pathogens with different levels of pathogenicity (i.e., the ability of an organism to cause disease). Some pathogens are highly pathogenic to the aquatic animal, for instance, pathogens of OIE-listed diseases such as IPNV, ISAV and IHNV. These pathogens often cause serious losses and there are no effective measures for control once the diseases have occurred. They must be strictly controlled by limiting the entrance through strict quarantine and/or complete eradication by killing all the infected aquatic animals. Other pathogens may have relatively weaker and even no pathogenicity, so-called secondary pathogens. They are common in the environment and cannot be completely removed from the environment. The proper methods for controlling the disease are by reducing the number of pathogens or the content of organic matter in the water environment using water disinfection.

Environmental factors are another important factor in the occurrence and development of aquatic animal diseases which affect both pathogens and animal health. A good environment condition is not only conducive to optimal aquatic health but also reduces the number of pathogens, which reduces the chances of diseases occurring. On the other hand, poor environmental or polluted conditions often increase the number of pathogens and cause stress to the animals, which reduces the resistance of aquatic animals and leads to diseases.

Finally, the general health status of the cultured species is also an important factor in the disease occurrence and development process. Generally, the better the health of animals means a stronger resistant ability to adverse environment conditions and infections, which leads to less possibility of disease occurrence, and vice versa. The animal health status or resistance ability is related to different factors, e.g. genetics, nutrition and not least immunological status. Therefore, the occurrence of aquatic animal diseases is the result of the combined effects of multiple factors. Comprehensive measures considering different aspect factors should be taken to prevent the occurrence of diseases.

Animal welfare is a growing concern, which addresses the "physical and mental health" and wellbeing of an individual or group (https://dictionary.cambridge.org/). Actually, there is no consensus or universal definition of animal welfare. One of the definitions agreed by most animal welfare scientists and laypeople are "Animal welfare equal to the quality of life as perceived by the animal itself" (Noble et al., 2018; Stien et al., 2013). There are many benefits to improving animal welfare and good welfare is usually correlated to making aquatic animals thrive, grow and stay healthy. Therefore, welfare is a broad concept including but not only for health or disease prevention and control. Besides, welfare is government ethics in many countries, for instance, the Norwegian Animal Welfare Act (2009) that protects all vertebrates (Noble et al., 2018). Given the broad concept, diseases are the central and main focus of this study, especially the biosecurity control of infectious diseases in salmonids.

5.2 General information on diseases of farmed salmonids

A variety of bacterial and viral pathogens as well as parasites can affect farmed salmonids. The major disease problems affecting Atlantic salmon vary with geographic location (Jones, 2004). The main reasons for the disease to develop are infections, unsuitable environment, and sub-optimal husbandry, etc. Pathogenic organisms include virus, bacteria, fungus and parasites. The most important viral diseases include ISA, VHS (Viral Haemorrhagic Septicaemia), IPN (Infectious Pancreatic necrosis) and PD (Pancreas Disease), of which VHS and IPN are important diseases to both Atlantic salmon and rainbow trout (Table 1) (FAO, 2011a, 2011b). The important bacterial diseases include Furunculosis, BKD (Bacterial Kidney Disease), Winter sores, ERM (Enteric Red Mouth), of which Furunculosis and BKD are important diseases to both Atlantic salmon and rainbow trout (Table 1). Other common disease problems are caused by pathogens like Salmon Rickettsia, saprolegnia, sea lice, gill amoeba and tapeworms (Fischer et al., 2017; Jones, 2004).

The OIE Aquatic Animal Health Code provides standards for the improvement of aquatic animal health worldwide. It gives member states recommendations for sanitary measures in relation to import and export “for the prevention, early detection, reporting and control of pathogenic agents in aquatic animals and to prevent their spread via international trade in aquatic animals and their products,” (OIE Aquatic Code). One of the key tools presented in the Aquatic code is to list notifiable diseases for fish that have to fulfill certain criteria (described in detail in Aquatic code, article 1.2.2). Key focus is on the global epidemiological status of the disease, level of consequences, e.g. morbidity or mortality at a population level, reduced productivity as well as ecological impacts.

Further, the Aquatic Code includes disease-specific chapters for these OIE listed aquatic animal diseases with biosecurity recommendations intended to eliminate or control the pathogenic agent in question. On the current OIE list of notifiable fish diseases, there are serious virus diseases known to infect salmonids e.g. ISA, PD, VHS, IHN, and epizootic haematopoietic necrosis (EHN) (OIE, 2020).

For Rainbow trout farming in China IHN is the main disease, needing a high level of government surveillance and sanitary measures (FAO, 2011b; OIE, 2020).

Besides pathogens, the unsuitable aquatic environment and other factors such as poor-quality feed, improper husbandry/operation can also cause severe disease problems. For instance, the hypoxia dead zones in the Gulf of Mexico and environmental shocks in Norwegian salmon production (Asche, Cojocaru, & Roth, 2018; Smith et al., 2017). Sub-optimal environment can favour pathogens thus increasing the risk of diseases developing. For instance, high temperature is one of the main environmental risk factors of amoebic gill disease (AGD) outbreaks with epizootics (Douglas-Helders, Saksida, Raverty, & Nowak, 2001).

5.3 Management measures for Atlantic salmon diseases

Diseases bring morbidity and/or mortality to farmed fish, which may lead to severe economic loss and social problems. Studies show that almost fifty percent of production loss is because of diseases which are more severe in developing countries (Assefa & Abunna, 2018). The annual loss of revenues because of disease reaches up to 6 billion dollars. For instance, ISA alone leads to 2 billion dollars in loss, while 15 percent of the total fish production loss is due to diseases, per year in China (Leung & Bates, 2013).

As “prevention is better than treatment,” it is advisable to focus on preventing the occurrence of a disease rather than treating it after it has happened. Since various reasons or factors might lead to diseases in aquaculture, a combination of different strategies rather than a single approach alone is more successful and effective in preventing and controlling diseases in aquaculture. The comprehensive approaches should focus on various aspects including pathogen control and eradication, improvement of the environment and health of the farmed animal as well. Many infectious diseases in salmon farming are effectively controlled using different combinations of control tools including chemical treatments, vaccination, the development of genetic resistance through breeding, and zoosanitary control measures. Among them, water disinfection and biological control, implemention of vaccination and antimicrobial compounds are the best approaches to control the infectious diseases of fish (Assefa & Abunna, 2018).

Antimicrobial compounds show a good effect on disease prevention and control, especially for some bacterial diseases. However, the use of antibiotics must be under strict control and regulatory measures because of drug resistance and residue related issues. In response to reduced antibiotic use in fish, vaccines get wide acceptance for the fact there is no risk of drug resistance development, which has been playing a key role in infectious disease control in aquaculture for decades. For instance, killed vaccines are used to prevent the infection of IHNV, *A. salmonicida*, and *V. salmonicida* while DNA vaccines are used to protect salmonids against economically important diseases such as IHN and VHS. In addition, *A. salmonicida* infection in Atlantic salmon can also be prevented by a live attenuated vaccine. Some vaccines that have been approved for use in salmonids are listed in Table 2. However, vaccines against intracellular bacterial and viral pathogens will be one of the big challenges for the coming years.

Besides antimicrobial compounds and vaccines, the use of probiotics, prebiotics, and medicinal plants in aquaculture have been confirmed to be effective methods in fish health improvement and disease prevention.

As for treatment strategies for infectious diseases in aquaculture, it can be classified into three basic types (Noble et al., 2018):

1. Controlling the disease by eradicating the infected fish,
2. Controlling the disease by living with the infectious agent,
3. No control but handling the recurrent costs associated with the disease.

The concrete measure chosen depends on the severity and development stage of the disease and the rules/regulations of the authority agency or government.

Table 1. Major diseases and parasites that can affect Atlantic salmon and/or rainbow trout.

Disease	**Pathogen**	**Type**	**Symptoms**	**Main sensitive species**	**References**
Viral Haemorrhagic Septicaemia, VHS	Rhabdovirus	Virus	Bulging eyes and, in some cases, bleeding eyes; pale gills; swollen abdomen; lethargy	Atlantic salmon, rainbow trout	FAO, 2011a, 2011b
Infectious Pancreatic necrosis, IPN	Birnavirus	Virus	Erratic swimming, eventually to bottom of tank where death occurs	Atlantic salmon, rainbow trout	FAO, 2011a, 2011b
Furunculosis	*Aeromonas salmonicida*	Bacterium	Inflammation of intestine; reddening of fins; boils on body; pectoral fins infected; tissues die on the back	Atlantic salmon, rainbow trout	FAO, 2011a, 2011b
Bacterial Kidney Disease, BKD	*Renibacterium salmoninarum*	Bacterium	Whitish lesions in the kidney; bleeding from kidneys and liver; some fish may lose appetite and swim close to surface; appear dark in colour	Atlantic salmon, rainbow trout	FAO, 2011a, 2011b
Infectious salmon anaemia, ISA	Orthomyxovirus	Virus	Lethargy; appetite loss; gasping at water surface; pale gills & heart; fluid in body cavity; dark liver; haemorrhages in internal organs	Atlantic salmon	FAO, 2011a
Pancreas Disease, PD	Togavirus	Virus	Weight loss; emaciation; mortalities	Atlantic salmon	FAO, 2011a, 2011b
Winter sores	*Moritella viscosa*, etc.	Bacterium	Ulcers	Atlantic salmon	FAO, 2011a
ERM (Enteric Redmouth)	*Yersinia ruckeri*	Bacterium	Black, lethargic fish 'hanging' in areas of low flow; bilateral exophthalmia; abdominal distension as result of fluid accumulation; haemorrhages of mouth and gills	Atlantic salmon	FAO, 2011a

SRS (Salmon Rickettsial Disease)	*Piscirickettsia salmonis*	Rickettsia	Increased mortality; anorexia; pale gills and lowered haematocrits; swollen abdomens; affected fish appear dark and lethargic, swimming at the sides of enclosures	Atlantic salmon	FAO, 2011a
Saprolegniasis	*Saprolegnia*	Fungus	White or grey patches of filamentous threads on surface; cotton-like appearance radiating in circular, crescent-shaped or whorled pattern; usually begins on head or fins	Atlantic salmon	FAO, 2011a
Sea lice	*Lepeophtheirus salmonis*, etc.	Parasite	Reduced growth; loss of scales; haemorrhaging of eyes and fins	Atlantic salmon	FAO, 2011a
Gill amoeba	*Paramoeba pemaquidensis*	Parasite	Gill infestation	Atlantic salmon	FAO, 2011a
Tapeworms	*Eubothrium* spp, etc.	Parasite	Reduced growth; reduced condition factor; aesthetically unacceptable to consumers	Atlantic salmon	FAO, 2011a
Freshwater protozoa	*Ichthyobodo*; *Trichodina*; etc.	Parasite	Irritation response; heavy and laboured operculum movements; flashing and rubbing; skin cloudiness caused by excess mucus; focal redness; lethargy	Atlantic salmon	FAO, 2011a
Algal/Jellyfish blooms	Various factors	Various	Various	Atlantic salmon	FAO, 2011a
Production diseases	Various factors	Various	Various	Atlantic salmon	FAO, 2011a
Infective Haematopoietic Necrosis, IHN	Novirhabdovirus	Virus	Erratic swimming eventually floating upside down whilst breathing rapidly after which death occurs; eyes bulge; bleeding from base of pectoral fins, dorsal fin and vent	Rainbow trout	FAO, 2011b
Furunculosis-like disease	*Aeromonas liquefaciens*	Bacterium	Smaller lesions on body that become open sores; fins become reddened and tissues break down	Rainbow trout	FAO, 2011b

Vibriosis	*Vibrio anguillarum*	Bacterium	Loss of appetite; fins and areas around vent and mouth become reddened; sometimes bleeding around mouth and gills; potential high mortality	Rainbow trout	FAO, 2011b
Bacterial gill disease	Myxobacterium	Bacterium	Loss of appetite; swelling and reddening of gills; eventually gill filaments mass together and become paler with a secretion blocking gill function in later stage	Rainbow trout	FAO, 2011b
White spot	*Ichthyophthirius multifilis*	Parasite	White patches on body; becoming lethargic; attempt to remove parasites by rubbing on side of tank	Rainbow trout	FAO, 2011b
Whirling disease (Myxosomiasis)	*Myxosoma cerebralis*	Parasite	Darkening of skin; swimming in spinning fashion; deformities around gills and tail fin; death eventually occurs	Rainbow trout	FAO, 2011b
Hexamitaisis Octomitis	*Hexamita truttae*	Parasite	Lethargic, sinking to bottom of tank where death occurs; some fish make sudden random movements	Rainbow trout	FAO, 2011b
Costiasis	*Costia necatrix*	Parasite	Blue-grey slime on skin which contains parasite	Rainbow trout	FAO, 2011b
Fluke	*Gyrodactylus* sp.	Parasite	Parasites attached to caudal and anal fins; body and fins erode, leaving lesions that are attacked by Saprolegnia	Rainbow trout	FAO, 2011b
Trematodal parasite	*Diplostomum spathaceum*	Parasite	Eye lens cloudy; loss of condition	Rainbow trout	FAO, 2011b

Table 2. Vaccines that have been approved for use in salmonids.

Sn.	**Vaccine name**	**Diseases prevented**	**References**
1	Infectious salmon anemia Vaccine	Infectious salmon anemia	(Caruffo, Maturana, Kambalapally, Larenas, & Tobar, 2016)
2	Infectious hematopoietic Necrosis Virus Vaccine	Infectious hematopoietic necrosis disease	(Anderson, Clouthier, Shewmaker, Weighall, & LaPatra, 2008)
3	Pancreas disease virus Vaccine	Pancreas disease	(Skjold, Sommerset, Frost, & Villoing, 2016)
4	*Aeromonas salmonicida* Bacterin	Furunculosis	(Antipa & Amend, 1977)
5	*Aeromonas hydrophila* Vaccine	Motile aeromonas septicemia	(Poobalane et al., 2010)
6	Arthrobacter Vaccine	Columnaris disease	(Shoemaker, Klesius, Drennan, & Evans, 2011)
7	Pasteurella Vaccine	Salmonid pasteurellosis	(Barnes & Ellis, 2005)
8	Enteric red mouth (ERM) Vaccine	Enteric red mouth disease	(Villumsen, Neumann, Ohtani, Strøm, & Raida, 2014)
9	*Yersinia ruckeri* Bacterin	Yersiniosis	(Tatner & Horne, 1985)
10	*Piscirickettsia salmonis* Vaccine	Piscirickettsiosis	(Evensen, 2016)
11	*Vibrio salmonicida* Bacterin	Vibriosis	(Hoff, 1989)
12	*Vibrio anguillarum-salmonicida* Bacterin	Vibriosis	(Hoff, 1989)
13	*Vibrio anguillarum-ordalii*	Vibriosis	(Boesen, Pedersen, Larsen, Koch, & Ellis, 1999)

6 BIOSECURITY AND ITS USE IN ATLANTIC SALMON FARMING INDUSTRY

6.1 Biosecurity in aquaculture

6.1.1 Biosecurity and its concept in aquaculture

In a broad sense, biosecurity refers to a nation's ability to respond effectively to biological threats and related factors (Zhou et al., 2019). Biosecurity is broadly defined by FAO as a strategic and integrated approach that encompasses both policy and regulatory frameworks aimed at analysing and managing risks relevant to human, animal and plant life, and health, as well as associated environmental risks (FAO, 2007). The risk covers the introduction and release of animal and plant infectious diseases and pests, living modified organisms and their products, and invasive alien species.

Biosecurity is essential for the health and welfare of the aquatic animal (Noble et al., 2018). The implementation of biosecurity measures is vital to the future sustainability of aquaculture, the protection of public health, the environment and biodiversity as well (Hine et al., 2010). Biosecurity principles for the prevention of aquatic animal diseases are modified from terrestrial animal health management. According to Moss (1998), the biosecurity in aquaculture is the sum of all procedures in place to protect living organisms from contracting, carrying, and spreading diseases and other non-desirable health conditions (Moss, Reynolds, & Mahler, 1998). At present, biosecurity in aquaculture mostly refers to the approach to minimise the risk of introduction, establishment and spread of pathogenic agents to, from and within an aquatic animal population at a facility, and to manage the adverse effects associated with contagious agents (Hine et al., 2010; Palić & Scarfe, 2018; Yanong & Erlacher-Reid, 2012). Good biosecurity measures will reduce the risk of catastrophic losses from infectious diseases, and benefit all stakeholders within the scope of disease management (Palić & Scarfe, 2018; Yanong & Erlacher-Reid, 2012). Control of transboundary aquatic animal diseases (TAADs) is the major biosecurity topics and trends because of the high ability of infection and the potential of rapid spread irrespective of national borders (Hine et al., 2010). Domestic and international trade are important pathways for the introduction of TAADs, by which pathogens may be introduced and spread to new areas and then cause serious socio-economic consequences.

OIE implements a biosecurity plan which encompasses both farmed and wild aquatic animals, exotic, endemic and emerging diseases to fulfill the management or prevention, control and eradication of the disease (Palić & Scarfe, 2018). The task of managing aquatic animal health and biosecurity governance is particularly challenging because of the great diversity of the aquaculture sector. Once a pathogen enters and settles in the aquatic environment, there is very little or no possibility for either treatment or eradication; therefore, prevention is the best strategy. Fish welfare is an important topic as it makes the fish thrive, grow and stay healthy, which benefits the disease prevention and control as well. Actually, the probability with which a specific pathogen can enter a facility and spread from one system to another and cause disease depends on the status of animal, environmental factors and pathogen characters and workers' understanding of biosecurity principles and compliance with biosecurity protocols. Therefore, the key focus in aquaculture biosecurity, as described by Yanong and Erlacher (2012), is:

1. Animal management – obtaining healthy stocks and optimising their health and immunity through good husbandry.

2. Pathogen management ‒ preventing, reducing or eliminating pathogens.
3. People management ‒ educating and managing staff and visitors.

6.1.2 Biosecurity plan on individual farms

A"Biosecurity Plan" is a plan that identifies significant potential pathways of the introduction and spread of diseases, and describes the measures applied in order to reduce the risks in a zone or compartment (Palić & Scarfe, 2018). The diseases usually referred to are the ones listed in the Aquatic Code. Based on it, the International Aquatic Veterinary Biosecurity Consortium (IAVBC) developed a biosecurity plan that should meet the needs of producers and government regulatory agencies. Biosecurity plans may be applied at different geographical levels from the site or farm to the region or to the national and even international level (Gudding, Lillehaug, & Tavornpanich, 2015; Lillehaug, Santi, & Østvik, 2015). Overall, the biosecurity plan at the farm level is one of the most important parts of the whole biosecurity system since fish farms are the main executors of farm biosecurity activities. Farm biosecurity work largely determines whether the whole biosecurity system is effective or not. Individually, fish farms usually need to exceed the compulsory government measures to achieve success and profit in a sound and sustainable business environment.

Disease prevention measures applied to aquaculture production systems are mainly based on risk analysis including hazard identification, risk assessment, and risk management, which is a decision-making tool in protecting industry development (Bondad-Reantaso, 2019; Lillehaug et al., 2015). The approach to IAVBC's plan focuses on applying several important core OIE processes aimed at determining and maintaining freedom from disease in any epidemiological unit (Palić et al., 2015). Epidemiologic Unit is a defined population of animals, separated to some degree from other populations, in which infectious and contagious diseases can be transmitted. (Palić & Scarfe, 2018; Palić et al., 2015). These processes include nine essential steps or key processes at five biosecurity levels (I to V), which are illustrated in Figure 6. In general, some biosecurity measures are compulsory (i.e., regulated by law) and must be followed by the entire industry while other procedures are recommendations, and implementation varies depending on individual farm or company (Palić et al., 2015). All the steps are important for developing any biosecurity plan tailored to specific epidemiological units. A biosecurity plan template developed by Yanong and Erlacher-Reid (2012) is listed in the appendix, which can be used as a guideline for the making of a biosecurity plan for an individual aquaculture facility.

6.2 Biosecurity in salmonid farming

Biosecurity focusing on reducing the introduction and spread of pathogens is increasingly accepted by the industry. Although biosecurity activities reduce short-run profits for the inevitable increase of production cost, it brings increased productivity and clear economic benefits from being declared free from many important diseases, which surely increases the industry's sustainability and long-run profits (Dresdner & Estay, 2016; Palić et al., 2015). There are many successful cases in the aquaculture industry, especially in the shrimp breeding industry, i.e., the specific pathogen free (SPF) shrimp breeding (Lightner, Redman, Arce, & Moss, 2009; Moss et al., 1998). Salmonid fish farming, especially Atlantic salmon farming benefits greatly from biosecurity activity. Many important diseases such as ISA, IPN, PD, VHS, and furunculosis have been controlled with various degrees through different biosecurity measures (Bondad-Reantaso, 2019; Gudding et al., 2015; Morton & Routledge, 2016). Considering the maturity and success of the Atlantic salmon industry, this section will focus on Atlantic salmon farming biosecurity as the representative of salmonids.

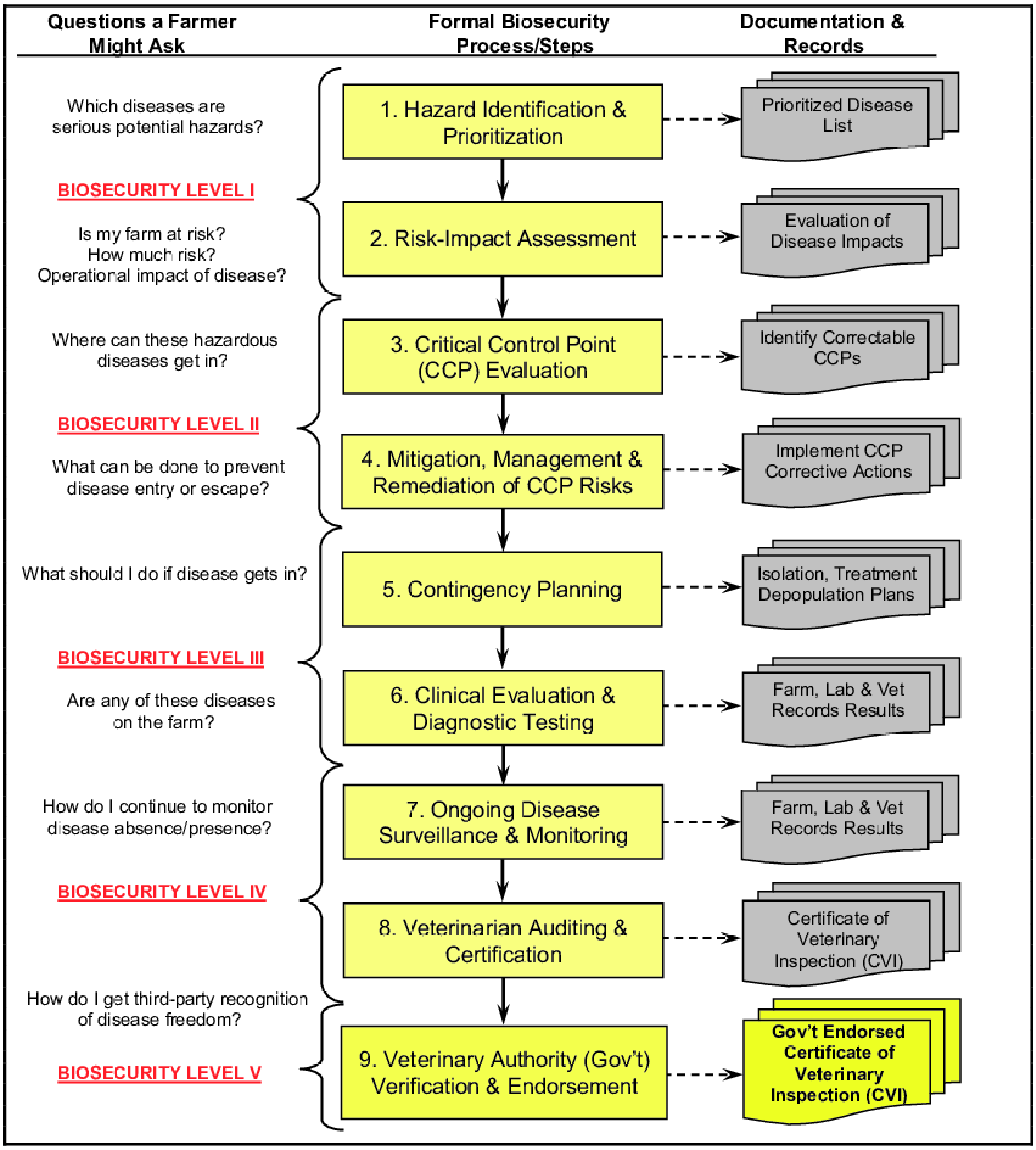

Figure 6. IVABC aquaculture biosecurity concept sheet (Palić & Scarfe, 2018).

Biosecurity plans usually apply broad principles of hygiene to control one specific infection or infectious agent, which will also protect against the introduction of others. Though, there are also some different biosecurity measures since the risk factors are different for different stages or environmental conditions. Atlantic salmon production can be divided into four stages: Smolt production in land-based tanks at the hatchery, market-size fish in sea site cage and/ or net pen, fertilised egg production in breeding stations and slaughtering in processing plants. The first three stages are the main processes of Atlantic salmon farming, which takes a key position in the biosecurity activities at the farm level. As the last stage of Atlantic salmon production, slaughtering may pose a significant risk of spreading pathogens to the surroundings while it is of minor importance to the bioexclusion in Atlantic salmon production (Jarp & Karlsen, 1997).

Generally, the water supply is of greatest potential risk for the introduction of pathogens during the whole production process. The risk may be reduced significantly by using water disinfection systems with UV light or ozone treatment during the smolt production stage and egg production (Kasai, Yoshimizu, & Ezura, 2002). The reduction of the supplemented water volume in RAS can reduce the risk of pathogens even further. For the market-size fish farming stage, the waterborne route of infection carried by wild fish and escapees cannot be controlled. Factors of importance are distance to other sea sites and installations (Kristoffersen, Viljugrein, Kongtorp, Brun, & Jansen, 2009).

For fertilised egg production, the criteria for choosing a location for seawater supply must be very strict regarding distance to other aquaculture installations, particularly sea farms, and the direction of water currents in relation to this. Broodstock farms with land-based tanks and borehole water, both fresh- and seawater, give even better biosecurity status. Live fish and vectors that include personnel and fomites coming into contact with infectious material (vaccinators, net cleaners, and wellboats) are also high-risk factors (Palić et al., 2015). It is of great importance to establish strict routines for hygienic control of all kinds of traffic into a fish farm area to minimise the risk. Different tools and equipment should be disinfected and used on one farm site only. The disinfection of eggs immediately after fertilisation and storage is generally practiced and even mandatory by law in some countries (Assefa & Abunna, 2018).

Lillehaug et al. (2015) summarised the potential risks for the introduction of infection into a fish farm through three main infection routes including live material, water source, and vectors. The infection routes are weighed against the levels of risk and illustrated in a matrix (Lillehaug et al., 2015). From the general risk overview matrix, sea caged fish, seawater and wellboats are of the highest-level risk for infection introduction. Lillehaug et al. (2015) also analysed the biosecurity risk pattern of the infection routes for introducing some important diseases including IPN, PD, ISA and ISA HPR0. HPR0 is a widespread low virulent variant of infectious salmon anaemia virus (Christiansen, Østergaard, Snow, Dale, & Falk, 2011; Jarp & Karlsen, 1997). Basically, sea caged fish, seawater and wellboats are also the highest risk factors for the introduction of those diseases (Lillehaug et al., 2015). Further, net cleaners have the highest risk for the introduction of IPN and PD while wild fish is one of the highest risk factors to ISA HPR0.

All the biosecurity matrices summed up by Lillehaug et al. (2015) including general risk overview and risk pattern of the specific disease are listed in the appendix section.

6.3 Biosecurity practice in Chinese salmonids farming industry

6.3.1 Biosecurity legislation in China

Biosecurity covers emerging infectious diseases, biological weapons and bioterrorism threats, misuse of biotechnology, alien species invasion, biological accident disclosure and super-resistant bacteria (Zhou et al., 2019). The first regulations related to biosecurity in China is "Methods on the Trial Management of the Preservation of Veterinary Microbial Strains" of the Ministry of Agriculture (MoA), which was implemented in 1980 and revised in 2004. During this period, China has had many measures related to work with pathogens dispersed among departmental rules and standards, but specific biosecurity laws and regulations have not existed.

The turning point occurred around 2003–2004 when Chinese authorities came to see that human health anxieties threatened national stability. By early 2007, the Chinese government had announced and implemented a series of revised and new biosafety regulations and standards. China has taken a full part in OIE activities since 2007, and through partnerships and personnel exchanges, China has integrated better with global preparedness and disease outbreak response efforts (Wei, Lin, & Hennessy, 2015). The fundamental law on animal disease prevention took effect after State Council regulations in 1997, and a major amendment took effect in 2008. Based on this law, the State Council established protocols for emergency response management, and for border quarantine (Xiang and Wang, 2011). The MoA’s Veterinary Bureau has formulated supportive rules for many activities, such as disease reporting and emergency response management. Now, China has developed a comprehensive veterinary regulatory and legal system, described by Wei et al. (2015).

In 2019, China started making biosecurity law which focused on protecting the security of the country's biological resources, promoting and safeguarding the development of biotechnology, and preventing and prohibiting the use of biological agents or biotechnology that may harm national security, which is the first biosecurity law of China (Gu, 2019). To address the need for both safeguarding security and development, the draft introduced regulations in eight categories:

1. The prevention and control of major emerging infectious diseases, animal and plant epidemics.
2. Research, development, and application of biotechnology.
3. Ensuring biosecurity in laboratories.
4. Ensuring the security of China's biological resources and human genetic resources.
5. Preventing the invasion of alien species and protect biodiversity.
6. Dealing with microbial drug resistance.
7. Preventing bioterrorism attacks.
8. Defending against the threat of biological weapons.

6.3.2 Biosecurity at the authority level in Chinese salmonid farming industry

Aquatic biosecurity framework consists of three levels, i.e., international level (WTO, OIE, FAO), national level (national government) and local level (local authorities, veterinary services, and producers) (Palić et al., 2015). Among this framework, OIE is the international body to provide international guidelines about animal diseases, which has recommended the development and implementation of general biosecurity procedures in the Aquatic Animal Health Code (OIE, 2020) and the Manual of Diagnostic Tests for Aquatic Animals (OIE, 2019). The national government and sometimes local authorities are responsible for the biosecurity measures at authority level by making and enforcing laws and regulations, which are the guidelines for the biosecurity activities at the farm level implemented by producers (Palić & Scarfe, 2018). These biosecurity rules at the authority level may be considered as minimum requirements or standards for aquatic industry biosecurity routines.

At present, many measures or concepts about biosecurity have been introduced into the Chinese aquaculture industry, especially in shrimp farming. However, there is scarce data or information available in the Atlantic salmon farming in China. It's important to collect the information on current biosecurity status in Chinese Atlantic salmon farming to develop practical advice with the questionnaire and other methods. According to the results of the questionnaire to government officers and the literature review, the main conclusions about the status of Chinese biosecurity at authority level are:

1. There are relevant general laws and regulations for farmed terrestrial animals, farmed aquatic animals including salmonids but there is still no specific biosecurity law or regulations for them, yet. These laws and regulations clearly state for the authority agencies, the requirements or criteria for the quarantine of aquatic seed import and daily surveillance during the salmonid farming process. The relative contents are listed in Table 3. Regarding the salmonid farming industry association, the "Strategic Alliance of Technology Innovation in Coldwater Fish Industry" is the main organisation in China that deals with the development and regulatory duties of the industry.

Table 3. Regulations or requirements related to salmonid biosecurity at authority level.

Process	**Requirements or regulations**	**Regulatory authority or agency**
Aquatic seed import	1. It can be imported from several specific countries or regions with the same criterion of quarantine. 2. Official General Health Certificate from the exporting country is needed. 3. Specific pathogen free (SPF) certification or test report is needed. The concrete diseases and test method according to the regulation of OIE.	1. Customs. 2. Ministry of Agriculture and Rural Affairs of PRC. 3. Provincial Department of Agriculture and Rural Affairs. 4. Municipality Fisheries administration department. 5. Municipality Aquatic animal disease prevention and control agency. 6. Municipality Supervision body for aquatic animal diseases.
Farming process	1. Both rainbow trout and Atlantic salmon need on-site surveillance and supervision. 2. The sampling frequency is 1-2 times per year, 150 fish per time for each farm. 3. The main disease (pathogen) monitored presently is IHNV. 4. Once diseases occur, destruction measure is applicable to IHN and other OIE-listed diseases. 5. Guided treatment for parasitosis caused by *Dactylogyrus*, *Aeromonas salmonicida* (furunculosis), *Ichthyophthiriasis*, et al.	1. Provincial Department of Agriculture and Rural Affairs. 2. Provincial Department of Aquatic Product Technology Promotion. 3. Monitoring, sampling, and testing agency commissioned by the Ministry of Agriculture and Rural Affairs of PRC.

2. Specifically, salmonid eggs or fry can be imported from several countries or regions with the same criteria which refer to the OIE's relevant regulations. Several agencies including Chinese customs, Ministry of Agriculture and Rural Affairs, Provincial Department of Agriculture and Rural Affairs and Municipality agencies are responsible for the quarantine and management of aquatic seed import into China. During the farming process, the main regulatory authority or agencies in China are the Provincial Department of Agriculture and Rural Affairs, Provincial Department of Aquatic Product Technology Promotion. Other monitoring, sampling and testing are commissioned by the Ministry of Agriculture and Rural Affairs of PRC. On-site surveillance and supervision requirements are listed in Table 3. Generally, regulations of OIE are the main reference for surveillance and with IHN currently being the most important disease of farmed salmonids in China, it should be thoroughly controlled.

6.3.3 Biosecurity at farm level in Chinese salmonid farming industry

Farm employees are the ultimate executors of a specific biosecurity plan at the farm level. Their knowledge and perception determine the effect of biosecurity activities. According to a survey made by Delabbio et al. (2015) among RAS fish farm employees in the USA and Canada the recognition including the beliefs, perceptions and attitudes of the human dimension element is more important than the biosecurity knowledge itself. Further, Jia, St-Hilaire, Singh, & Gardner (2017) made a survey on biosecurity practices in the Chinese yellow catfish farming industry reaching the same conclusion. However, there is very limited information on the biosecurity routines and practices in the Chinese salmon farming industry. A questionnaire on biosecurity at the farm level was conducted to survey the knowledge and practices of biosecurity in the salmonid industry in China.

Background of survey respondents

Two Atlantic salmon farms were selected, and both are the main Atlantic salmon farms in China. Six rainbow trout farms, located in the northeast, southwest, and northwest of China were also selected. The scale of the farms' production volumes was also an important factor to consider. One sharp-snouted lenok farm and one Coho salmon farm were also selected for the completion of different salmonid species being farmed in China. The general information about the selected farms is listed in Table 4. For the production systems, both Atlantic salmon and Coho salmon farms use the land-based RAS production systems while rainbow trout are raised in both cages and land-based flow through systems. The sharp-snouted lenok farm uses a land-based flow through the system only. The scale of production (yield) of the above companies ranges from 200 tonnes to 13,000 tonnes with the output value from approximately 0.4 to 73 million dollars per year.

In total, 44 survey responses were received and thereof 31 respondents were valid, i.e. the whole questionnaire was answered. The content of these was used for further analysis. The valid respondents included 15 from farm management, 9 with biology/technician roles, and 7 workers/operators. The relative distribution of the respondents' farm roles is demonstrated in Figure 7 showing the managerial part of the respondents to be 48%.

In terms of personal educational background, most of the respondents have a good educational background ranging from high school to postgraduate. Almost everyone (30 of 31) had received an academic education and/or formal training on aquaculture and/or fish diseases. In general, the biology/technician employees had the best education level with 66.7% having either undergraduate or postgraduate education while undergraduate education among workers/operators was 16.7%. From the view of farming different salmonid species, people that work in the Atlantic salmon industry have better educational background than those working on rainbow trout, Coho salmon or sharp-snouted lenok farms. 80% of the personnel that worked in Atlantic salmon farms were bachelor or master's degree graduates while the portion in the rainbow trout, Coho and lenok farms was only 23% (Figure 8), with 6% master's degree graduates and 17% bachelor degree graduates, respectively.

Analyses were conducted on the results of the questionnaire given by the respondents using Fisher exact tests to assess whether there is a relationship between the personnel's educational background towards the salmonid industry. The results of Fisher exact tests showed that there is a significant difference between the Atlantic salmon and rainbow trout industry in the individual education level background ($p<0.05$).

Table 4. Basic information in the questionnaire.

No.	**Main species and Production systems**	**Culture volume (m^3)**	**Production scale (tonnes)**	**Output value (million $)**
1	Atlantic salmon, Land-based RAS	9.2	400	2.34
2	Atlantic salmon, Land-based RAS	36.8	700	6.13
3	Coho salmon, Land-based RAS	10	200	1.46
4	Rainbow trout, Cage	60	1320	11.68
5	Rainbow trout, Cage	460	3000	21.90
6	Rainbow trout, Cage	3670	13000	72.99
7	Rainbow trout, Land-based flow through system	4.2	150	0.44
8	Rainbow trout, Land-based flow through system	8	200	1.05
9	Rainbow trout, Land-based flow through system	250	1000	4.38
10	sharp-snouted lenok, Land-based flow through system	5	5	0.44

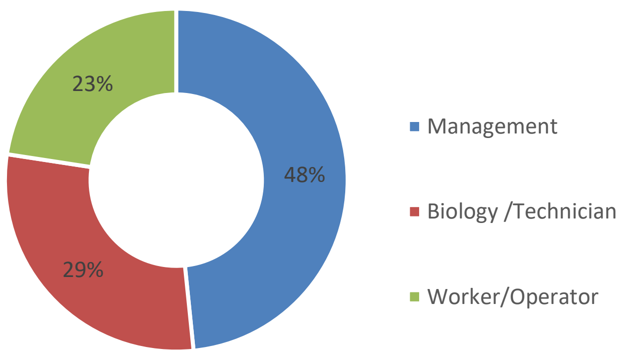

Figure 7. Relative distribution of respondents' role in the salmonid industry

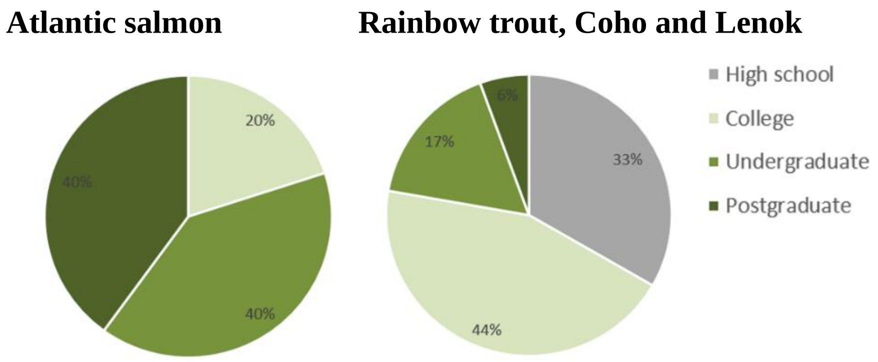

Figure 8. Personnel education level in Atlantic salmon and rainbow trout farms.

Knowledge about farm biosecurity

Respondents were asked to grade the importance of biosecurity while performing their daily husbandry routine. Most of the respondents (more than 90%) had heard of different types of diseases. The results from the respondents also indicated obvious differences about which type of diseases they had heard about (Table 5). However, regarding specific types of diseases, the respondents knew less about viral diseases of salmonid fish (Figure 9). In more detail, only 6% of the respondents had heard about virus diseases while the percentages relating to bacteria diseases, parasites diseases and fungal diseases were 64%, 55%, and 38%, respectively. Most respondents knew more about diseases with obvious and visible symptoms frequently seen in parasitic and fungal diseases. Further, their knowledge or information about Aquatic Health Management agencies is insufficient. Only seven respondents knew about OIE and eleven respondents knew about the local agencies work with farmed fish. Differently, thirteen respondents did not have any knowledge of international or governmental agencies dealing with aquatic health matters.

Most of the respondents seem to have good knowledge of biosecurity or disease management as a part of routine farm practices. Things like using a biosecure water source, disinfecting eggs, frequently netting up dead and moribund fish, etc., were the items that many of the respondents focused on. But in general, the attention to overall biosecurity management was somewhat limited. Things like visitor logbook, limitation on visits, general hygiene practices seemed not very important to almost half of the respondents regarding farm biosecurity routines. There was also surprisingly little interest in the topic of control measures for the potential risk factors including "All-in, all-out" stock management, "Pest Control" and "Do not mix year classes on a farm".

Analyses were conducted on the results of the questionnaire given by the respondents using Fisher exact tests to assess whether there is a relationship between the personnel's biosecurity knowledge towards the salmonid industry. The results of Fisher exact tests showed that there is no significant difference between Atlantic salmon and other salmonid trout industry in the biosecurity practice ($p>0.05$).

Table 5. The respondents' familiarity with different types of aquatic diseases/health problems.

Type of diseases/health problems	Have you heard of the disease?		
	Yes	Not sure	No
Viral diseases	2	11	18
Bacterial diseases	20	7	4
Fungal diseases	10	8	13
Parasitic diseases	17	10	4
Suboptimal environment	4	10	17
Suboptimal feed/nutrition	5	8	18
Genetic abnormalities	5	10	16

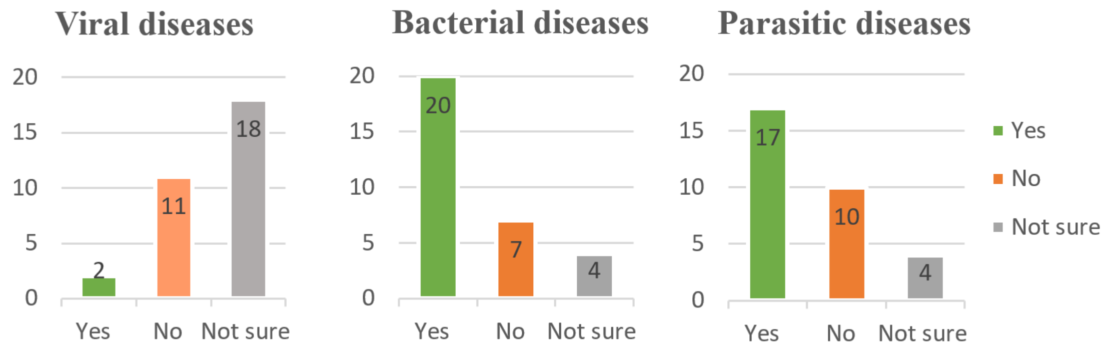

Figure 9. The respondents' familiarity with different types of infectious diseases.

Practice about farm biosecurity

Respondents were asked to access their biosecurity activities during their daily husbandry routine work. Almost all of the respondents pay enough attention to the measures relating the diseases management directly, such as limiting purchases from a few sources with known and trusted fish health programs and not stocking new fish from farms with disease outbreak, disinfecting eggs upon arrival to the farm, monitoring the fish status closely and frequently, knowing the health status and the source and so on. However, some potential risks for pathogens importing were not controlled well for some respondents (Figure 10). For instance, newly acquired or returned fish was not required to be quarantined at least 3 weeks by 19.5% of the respondents. In addition, only 61.3% of the respondents limited their visiting to the farms with disease-outbreaks strictly. 32.3% of the respondents did not limit access to the visit, and even further, 16.1% of the respondents did not forbid the visit of farmers from the farms with disease-outbreaks.

Analyses were conducted on the results of the questionnaire given by the respondents using Fisher exact tests to assess whether there is a relationship between the personnel's biosecurity practice towards the salmonid industry. The results of Fisher exact tests showed that there is no significant difference between Atlantic salmon and rainbow trout industry in the biosecurity practice (p>0.05).

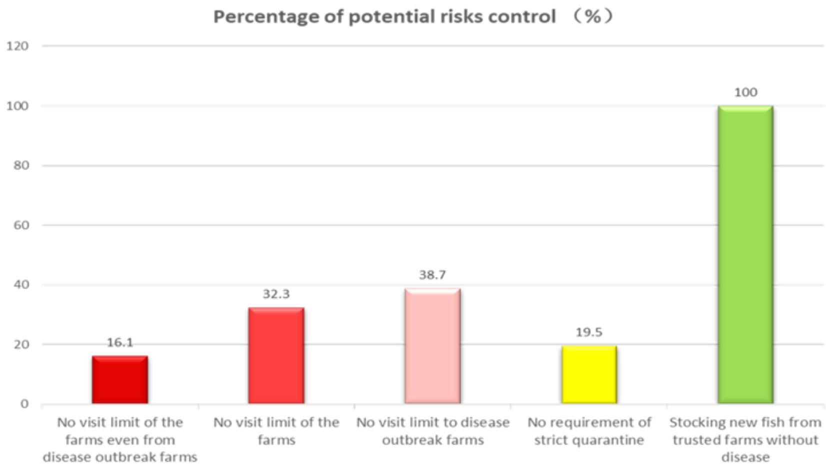

Figure 10. Percentage of potential risks control.

7 BIOSECURITY MANAGEMENT ADVICE TO CHINESE INDUSTRY

Aquatic biosecurity is a systematic framework focusing on risk identification, risk assessment and risk management in the aquaculture industry, which plays a vital role in the sustainability of aquaculture, and food, ecology and social safety as well. General biosecurity procedures in aquatic, which have been suggested in the Aquatic Animal Health Code (OIE, 2020) and the Manual of Diagnostic Tests for Aquatic Animals (OIE, 2019), are the international guidelines developed by OIE. The national government and sometimes local authorities make and enforce laws and regulations to fulfill the requirement of international guidenlines, while producers are the ultimate executors of a specific biosecurity plan under the guidance of the government laws and regulations (Palić & Scarfe, 2018). With reference to the biosecurity experience of the international salmon farming industry, combined with the concrete status of the Chinese salmonid farming industry, the biosecurity management advice including both authority level and farm level are given to Chinese salmonid industry.

7.1 Advice to Chinese salmonid farming industry at the authority level

According to the current status of Chinese salmonid biosecurity at the authority level, the advice is:

1. Further improve the biosecurity laws and regulations. Considering the particularity of the aquaculture industry, the legislation of aquaculture biosecurity and even specialisation in the salmon industry is necessary in the future.

2. Optimise and further integrate the authority agencies and their function. There are too many authority agencies that create complexity and make the governmental management inefficient and difficult for the producer to seek help or guidance.

3. Strengthen the enforcement of biosecurity laws and regulations. Ensuring all laws and regulations are enforced strictly and under uniformed standards in the whole country.

4. Strengthen the knowledge of biosecurity laws and regulations, enlighten the governmental stakeholders more about biosecurity and its vital role in the aquaculture industry.

5. Promote and assist the industry to create and implement a biosecurity certification plan as an important part of increasing the awareness for a biosecure and sustainable salmon production.

7.2 Advice to Chinese salmonid farming industry at the farm level

According to the current status of Chinese salmonid biosecurity at the farm level, the advice is:

1. Increase the level of knowledge with systematic training for the fish farm employees including the managers, biologists/technicians and workers to improve their biosecurity knowledge. And for increasing the motivation, focus should be put on their beliefs, perceptions and attitudes towards the different aspects of biosecurity.

2. Strengthen the understanding of major diseases and their hazards both locally and in the global salmon industry in general, especially the diseases specified by the OIE.

3. Pay continuous attention to the potential risks for importing pathogens into a farm in the context of biosecurity routines, including strict quarantine and/or mitigation measures for everything brought into a farm, that being a live fish, water or fomites.

4. Ensure quality in general hygiene practices as well as with routine sanitation measures needed for a biosecure farm environment.

5. Finally, the making of a detailed biosecurity plan for a fish farm, the individual farm site and even for different sections of a hatchery, should be a collective teamwork preferable with guidance by a veterinarian or a fish health professional. Every biosecurity plan should be revised annually, at least.

ACKNOWLEDGEMENTS

First of all, I would like to extend my appreciation to UNESCO - FTP for providing me with the opportunity to be a part of this programme.

My thanks and sincere gratitude to my supervisor, Bernhard Laxdal, for his guidance and assistance throughout the project. His knowledge reserve in the aspect of fish heath and fish biosecurity enlightens me not only in this project but also in my future study.

I shall extend my thanks to Dr. Tumi Tomasson, Mr. Thor H Asgeirsson, Ms. Mary Frances Davidson, Ms. Julie Ingham, Mr. Stefan Ulfarsson and Ms. Beata Beata Wawiernia for their continuous assistance and support. I will also express my thanks to Mr. David Benhaim, Ólafur Sigurgeirsson and other staff in the Department of Aquaculture and Fish Biology of Hólar University for their guidance, assistance and friendship during my stay in the beautiful place, Saudarkrokur.

I also want to thank leaders of Dalian Ocean University (DLOU) for offering this training opportunity. Thanks are also delivered to my colleagues in the College of Fisheries and Life Science for their support during my leave.

Last but not least, I would like to express sincere gratitude to my wife, Mina Ai, and our son Mingze Ye, for their continuous patience and support from a distance. Also, I wish to express my gratitude to other family members and friends for their support and encouragement.

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APPENDICES

Appendix 1: Questionnaire for Authority or Governmental Management

Questionnaire for Authority or Governmental Management

To: Chinese government officers who responsible for biosecurity matters

1. Is there a specific salmonid farming association or other relevant organisation in China that undertakes the development and regulatory duty of the salmonid farming industry?

❑ No

❑ Yes, please specify ________________________________

2. Which department is responsible for the quarantine and management of aquatic seed import in China?

❑ Customs
❑ Ministry of Agriculture and Rural Affairs of PRC
❑ Provincial Department of Agriculture and Rural Affairs
❑ Provincial Department of Aquatic Product Technology Promotion
❑ Aquatic Industry Association

❑ Other Agency, please specify ______________________

3. Are there any biosecurity laws or regulations for farmed terrestrial animals, aquatic animals and/or farmed salmonids only in China?

❑ There are special biosecurity laws and regulations for farmed terrestrial animals

❑ There is no specific biosecurity law or regulation but other relevant general laws and regulations for farmed terrestrial animals

❑ There are special biosecurity laws and regulations for farmed aquatic animals

❑ There is no specific biosecurity law or regulation but other relevant general laws and regulations for farmed aquatic animals

❑ There are special biosecurity laws and regulations for farmed salmonids

❑ There is no biosecurity law specific to farmed salmonids but other relevant general laws and regulations specific to farmed salmonids

❑ There is neither biosecurity law nor general laws or regulation applicable to farmed salmonids

4. What's the requirement or criteria of the import of salmonid eggs or fry to China?

❑ No specific criteria yet

❑ It can be imported from any country with the same criterion

❑ It can be imported from several specific countries or regions with the same criterion

❑ It can be imported from specific countries or regions only, and the requirements are different between countries or regions

❑ Other, please specify ______________________________

5. Are any certifications or qualifications needed when salmonid eggs or seedlings are imported to China?

❑ No specific import documentation needed

❑ Official General Health Certificate from the exporting country

❑ Specific pathogen free (SPF) certification or test report

If SPF certification is needed, please specify the concrete diseases and test method :

________________ (___________), ________________ (___________),

________________ (___________), ________________ (___________),

________________ (___________), ________________ (___________),

❑ No SPF certification or test report needed

6. During the farming process, the main regulatory authority or agency in China is

❑ Ministry of Agriculture and Rural Affairs of PRC
❑ Provincial Department of Agriculture and Rural Affairs
❑ Provincial Department of Aquatic Product Technology Promotion
❑ Aquatic Industry Association

❑ Other Agency, please specify ________________________________

7. Status of the surveillance of salmonid farming during the farming process

❑ Rainbow trout, not yet included in the monitoring program

❑ Rainbow trout, which requires surveillance

❑ Including on-site surveillance and supervision, please specify:

The diseases monitored include _____________________________ ;

The sampling frequency is _________________________________ ;

The sample size is ____ .

❑ Atlantic salmon, not yet included in the monitoring program

❑ Atlantic salmon, which requires surveillance

❑ Including on-site surveillance and supervision, please specify:

The diseases monitored include _____________________________ ;

The sampling frequency is _________________________________ ;

The sample size is ____ .

8. The guidance from the regulator agency when diseases outbreak in salmonid farming

❑ Rainbow trout, no specific provisions

- ❑ Rainbow trout, with specific regulations.

  Destruction, applicable to ________________________________ ;

  Distribution ban/limitation _______________________________ ;

  Guided treatment for ____________________________________ .

- ❑ Atlantic salmon, no specific regulations
- ❑ Atlantic salmon, with specific regulations.

  Destruction, applicable to _______________________________ ;

  Distribution ban/limitation ______________________________ ;

  Guided treatment for ___________________________________ .

Thank you for participation in the survey! Data will be kept confidential and summarised results will be shared with all participants at the end of the study.

Appendix 2: Questionnaire for Biosecurity at Farm Level

Questionnaire for Biosecurity at Farm Level

To: General Manager, Biology/Technician and Workers/Operator in Rainbow trout or Atlantic salmon farm in China

Basic Information	
General Information of the Farm	❑ Atlantic salmon, Land-based RAS ❑ Atlantic salmon, Cage culture ❑ Rainbow trout, Land-based, flow through system ❑ Rainbow trout, Cage culture ❑ Other, please specify ________________________
	Aquaculture water area __________________________ Annual production ______________________ (Metric Ton) Annual production value ________________ (RMB)
Position of the Respondents	❑ Management ❑ Biology /Technician ❑ Worker/Operator
Academic education	❑ Elementary school ❑ Junior high school ❑ High school ❑ College ❑ Undergraduate ❑ Postgraduate
	Do you have formal training in aquaculture? ❑ Yes, please specify__________________________ ❑ No
Experience in aquaculture	❑ ≤1 ❑ 1 ~ 2 ❑ 2 ~ 5 ❑ 5 ~ 10 ❑ ＞10 (Years)

Knowledge of Disease Management and/or Biosecurity

1. Have you heard of any infectious disease of rainbow trout or Atlantic salmon?

❑ Yes ❑ No ❑ Not sure

2. Have you heard of any salmonid diseases related to suboptimal environmental conditions such as poor water quality, too high temperature and so on?

❑ Yes ❑ No ❑ Not sure

3. Have you heard of any salmonid diseases related to suboptimal feed/nutrition

❑ Yes ❑ No ❑ Not sure

4. Have you heard of any salmonid diseases related to genetic reasons

❑ Yes ❑ No ❑ Not sure

5. Have you heard of any Aquatic Health Management agencies (International and/or Chinese ones)?

❑ OIE ❑ Chinese agency, please specify__________________

❑ Other, please specify__________________ ❑ No

6. Please identify what diseases *you feel are most important* to Atlantic salmon or rainbow trout on your farm? List the top 5 in order of *your* priority:

Rainbow trout	Atlantic salmon
R1: ______________________________	A1: ______________________________
R2: ______________________________	A2: ______________________________
R3: ______________________________	A3: ______________________________
R4: ______________________________	A4: ______________________________
R5: ______________________________	A5: ______________________________

Other diseases of concern ____.

7. Have you had one or more of the following type of fish diseases on your farm in last year?

	The cause of the diseases	Yes	No	Not sure
7.1	Viral diseases			
7.2	Bacterial diseases			
7.3	Fungal diseases			
7.4	Parasitic diseases			
7.5	Suboptimal environment			
7.6	Suboptimal feed/nutrition			

7.7	**Genetic abnormalities**			

8. How important the statements below are for the farm biosecurity? Please grade the statements from 1 to 5, with "1" being of little biosecurity value while "5" being of the greatest biosecurity value.

8.1 Visitors logbook/ limitation on farm visits
❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5

8.2 Closed tanks/in-house farm compared to open pond farm facility

❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5

8.3 Only certified salmonid eggs brought on to the farm
❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5

8.4 Pathogen free water-source
❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5

8.5 Keep tanks/cages clean and tidy
❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5

8.6 Boot and hand disinfection between farm divisions
❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5

8.7 Good knowledge of biocidal & chemicals
❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5

8.8 "All in - All out" practices
❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5

8.9 Improving water quality
❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5

8.10 Pest control
❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5

8.11 Do not mix year classes on farm
❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5

8.12 Good knowledge of fish pump machinery
❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5

8.13 Regular screening for disease/pathogen in the stock
❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5

8.14 Continuous Risk assessment to support the farm's Biosecurity system
❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5

8.15 Buying fish feed from a reliable source with quality control
❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5

8.16 Regular seminars and courses on health and biosecurity

❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5

8.17 Netting up sick or dead fish and disposing of them in a secure way

❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5

8.18 Good production/farming plan

❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5

8.19 Regular veterinary visits/surveillance on the farm

❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5

8.20 Each tank/cage unit with its own handnet and other necessary equipment

❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5

Practices of Disease Management and/or Biosecurity Measures

1. Have you restricted or stopped all fish movement on or off your farm to prevent entry or spread of any disease?

❑ Yes ❑ No ❑ Not sure

2. Have you implemented strict biosecurity measures for fish water sources, equipment, vehicles, wildlife vectors and people on your farm?

❑ Yes ❑ No ❑ Not sure

3. Are you closely and frequently monitoring your fish for signs of disease?

❑ Yes ❑ No ❑ Not sure

4. Do you limit contact between your fish stock and wild fish stocks?

❑ Yes ❑ No ❑ Not sure

5. Do you limit the frequency and number of new introductions of fish onto your farm?

❑ Yes ❑ No ❑ Not sure

6. Do you limit purchases to a few sources with known and trusted fish health programs?

❑ Yes ❑ No ❑ Not sure

7. Do you know the health status and the source of the fish brought onto your farm?

❑ Yes ❑ No ❑ Not sure

8. Do you only bring aquatic animals onto your farm, that have been inspected or tested to be free of the listed diseases?

❑ Yes ❑ No ❑ Not sure

9. Do you request copies of health certificates, vaccination and treatment records (if applicable) for all purchased fish?

❑ Yes ❑ No ❑ Not sure

10. Do you disinfect eggs upon arrival to the farm?

❑ Yes ❑ No ❑ Not sure

11. Do you require that newly acquired or returned fish for your farm are quarantined for at least 3 weeks upon arrival?

❑ Yes ❑ No ❑ Not sure

12. Are your quarantine facilities separate from all other fish areas?

❑ Yes ❑ No ❑ Not sure

13. Do prevent the sharing of water, facilities or equipment between newly acquired or returned fish and your currently stocked fish?

❑ Yes ❑ No ❑ Not sure

14. If equipment must be used elsewhere on the farm, do you clean and disinfect the item before moving it from one location and another location?

❑ Yes ❑ No ❑ Not sure

15. Do you limit access to your farm?

❑ Yes ❑ No ❑ Not sure

16. Do you have only one gated entrance to fish production areas on your farm to better control and monitor visitors and vehicles?

❑ Yes ❑ No ❑ Not sure

17. Do you keep the gate locked when not in use?

❑ Yes ❑ No ❑ Not sure

18. Have you posted signs at the farm entrance to inform visitors to stay off your farm unless they have received permission?

❑ Yes ❑ No ❑ Not sure

19. Is traffic on or off your farm closely monitored and recorded?

❑ Yes ❑ No ❑ Not sure

20. Do you maintain a log sheet to record any visitors or vehicles that come onto your farm?

❑ Yes ❑ No ❑ Not sure

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21. Do you require delivery vehicles and visitors follow your farm biosecurity guidelines regarding parking and fish contact?

❑ Yes ❑ No ❑ Not sure

22. Do you visit farms after knowing their disease-outbreaks occurrence?

❑ Yes ❑ No ❑ Not sure

23. Do you forbid farmers from farms of disease outbreak to visit your farm?

❑ Yes ❑ No ❑ Not sure

24. Do you stock new fish from farms with disease outbreaks?

❑ Yes ❑ No ❑ Not sure

Thank you for participation in the survey! Data will be kept confidential and summarised results will be shared with all participants at the end of the study.

Appendix 3: Biosecurity plan template

Basic Biosecurity Plan Template

Use the following as a template for a general biosecurity plan and adjust it according to the concrete conditions.

1. Which species is/are being cultured?
2. Draw a schematic of the farm. Include each building and each system, entry and exit points, and major flow patterns (fish movement, visitor and employee movement). Identify the life stages (eggs, juveniles, adults) found in each system.
3. System (pond, tank) management and husbandry
   - How will the system be managed to ensure good water quality/chemistry for the species?
   - Is the system appropriate for the given species, life stage, and density?
   - Can individual units be effectively isolated in the event of an outbreak?
   - Is cleaning the system easy?

Changes should be made where possible to correct any problems.

4. What are the important infectious diseases for the species cultured?
5. Where can these disease-causing agents be found or how can they enter the farm?
   a. Water source: safe (biosecure) or unsafe (not biosecure)?
   - If safe (from a deep well, municipal supply, or originally from an unprotected source but disinfected before use), your water should pose little or no risk. Note: Water from a safe source is not always the best quality for the species being raised and may need to be treated.
   - If unsafe (from a shallow well or surface water), how will it be disinfected?

   b. Fish:
   - Identify a limited number of well-known, reputable suppliers.
   - Have suppliers provided information on the health status of new fish?
   - Have their fish been tested for specific diseases?
   - How will you quarantine new fish and have them tested for specific pathogens of concern if necessary?
   - How will you isolate sick fish from the rest of the population?

   c. Diet/Nutrition:
   - Identify reputable sources for live and frozen foods.
   - Where will you store commercially prepared feeds?
   - Who is responsible for labelling and dating stored feeds?
6. How can diseases be spread? They can be spread by fish, water, pests, other animals, food, people, and equipment.

- How will the system be designed to separate different “lots” of fish?
  A “lot” of fish is a unit of animals of the same species, and usually the same life stage, that is managed as one group during production. Different lots of fish should be physically separated, with fish of similar biosecurity status and age closest to each other and those of unknown or differing status (broodstock vs. fingerlings vs. eggs) most separate, which should be considered of the same health and disease status and susceptibility.
- Where should signs be posted to identify different security zones on the farm and to restrict the movement of employees and visitors?
- Are there disinfectant footbaths and hand washing stations at the entrances to different buildings and zones? Should there be protective clothing (coats, boots) that is dedicated to a specific building as an added precaution?
- Who is responsible for cleaning and disinfecting equipment between uses? (Each system should have clearly labelled and dedicated equipment.)

- How will pests and predators (rats, insects, birds, otters, snakes, turtles) be controlled?
- How will pets and livestock be prevented from moving from one system (pond or tank system, area of different biosecurity status) to another?
- When will feeds be inspected so that out-dated or possibly contaminated feeds can be discarded?

7. Management of disease outbreaks

- What is the plan for observing fish daily for changes in feeding, behaviour or appearance that might indicate a disease outbreak?
- What steps will be taken if there is a disease outbreak?
    - ■ Signs posted
    - ■ Investigation (water quality, nutrition, disease diagnostics)
- Are diagnostics and tests used to determine which legal drugs and chemicals to use for treatment?
- Who will notify authorities for reportable diseases?
- How will dead fish be disposed of to meet local, state and federal regulations?
- How will discharge from diseased systems be treated and/or disposed of to meet local, state and federal regulations?
- How will the facilities be cleaned and disinfected to eliminate any pathogen reservoirs in holding areas, on equipment, or on any other surfaces?

(to be continued)

8.Records

Records are important legal documents that can demonstrate facility operation and production as well as system isolation during reportable disease outbreaks.

- Keep records of water quality parameters, changes of footbath and net dip solutions, feed expiration dates, animal inventory, fish disease outbreaks (including dates and number dead per day), disease investigation findings, and use of drugs and chemicals (including expiration dates and when used).

9. Biosecurity plan evaluation

The plan should be assessed at least once a year for effectiveness and compliance. Appropriate and up-to-date records will provide information about the increase or decrease in the number of losses, the use of drugs and chemicals, and sales.

Producers developing biosecurity plans should begin by examining their goals and evaluating the related risks. Biosecurity management should target the most important areas and pathogens/diseases to be protected against and implement strategies that are effective and practical. Compliance and documentation are the big challenges to a successful plan. Everyone working in or with a facility needs to have ownership in the plan and recognize why specific procedures are in place.

(Source：Adapted from Yanong et al., 2012)

Appendix 4: Biosecurity matrices of infection risk into a farm

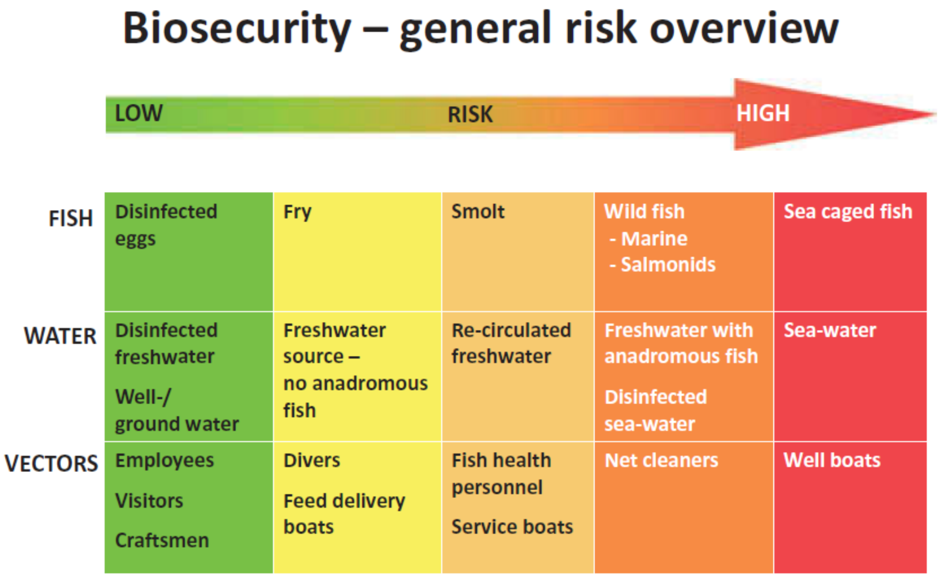

Figure 1. Potential risks for the introduction of infection into a fish farm. The three main categories of infection routes (live material, water source, and vectors) are weighed against levels of risk. Lowest risk is to the left (green), increasing toward the right (red). (Lillehaug et al., 2015)

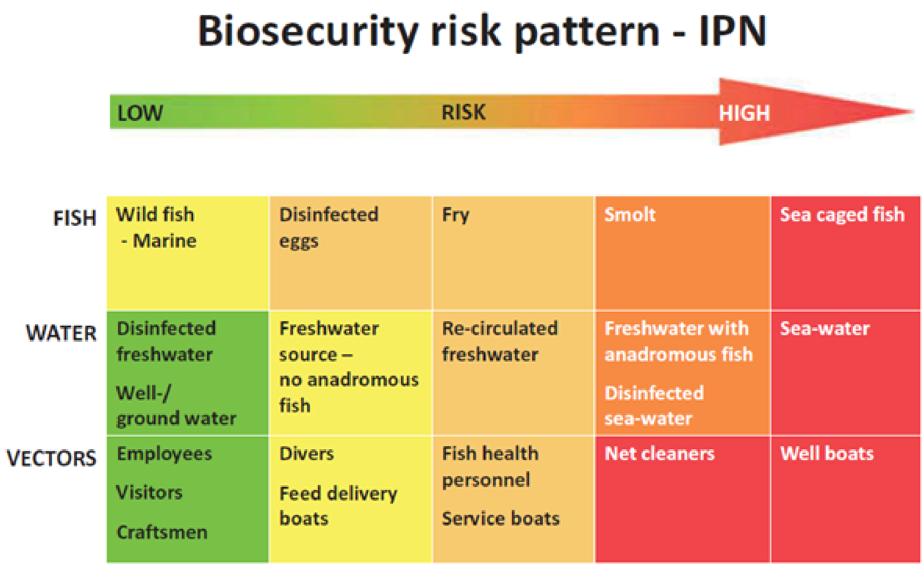

Figure 2. Level of risks for the introduction of infectious pancreatic necrosis (IPN) virus into an Atlantic salmon production site. Lowest risk is to the left (green), increasing toward the right (red). (Lillehaug et al., 2015)

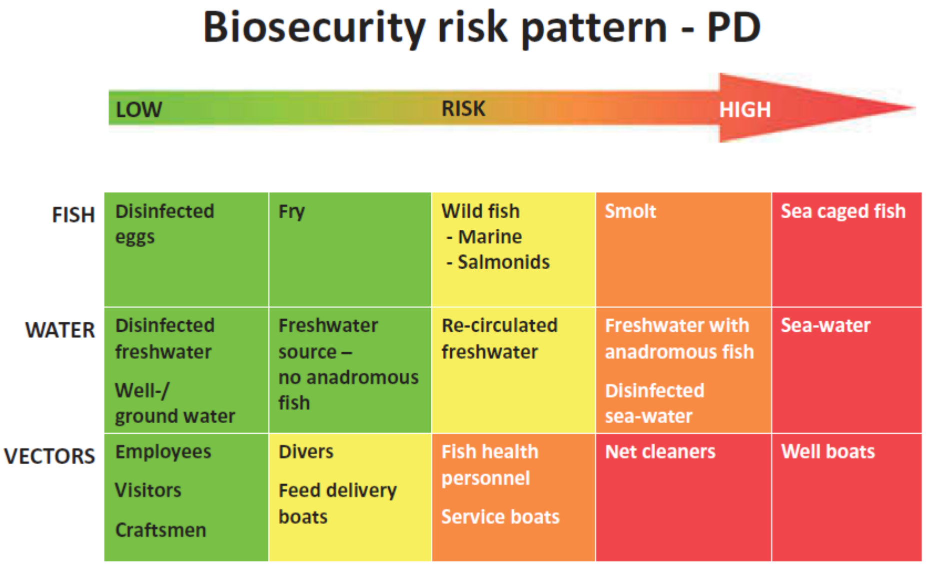

Figure 3. Level of risks for the introduction of pancreas disease (PD) virus into an Atlantic salmon production site. Lowest risk is to the left (green), increasing toward the right (red). (Lillehaug et al., 2015)

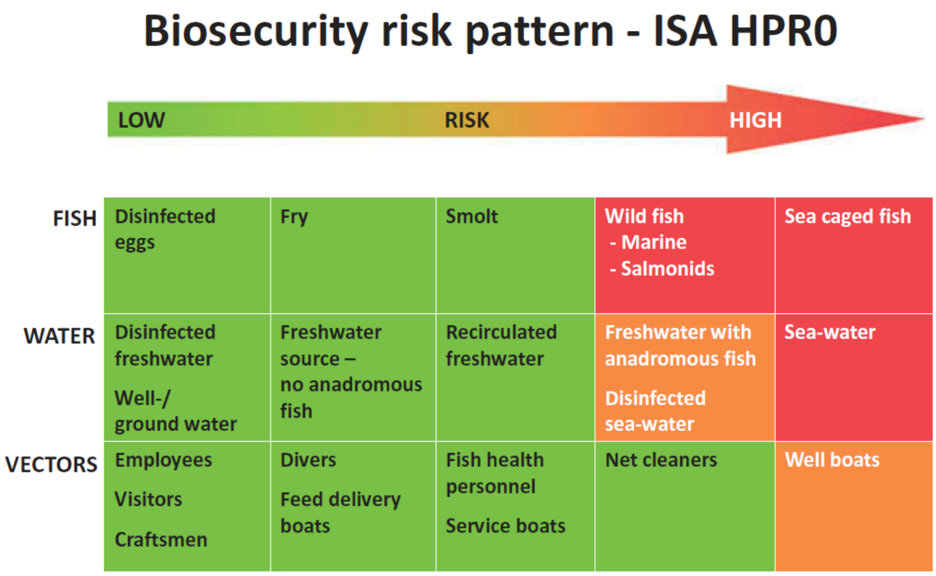

Figure 4. Level of risks for the introduction of low virulent infectious salmon anaemia (ISA) virus (HPR0) into an Atlantic salmon production site. Lowest risk is to the left (green), increasing toward the right (red). (Lillehaug et al., 2015)

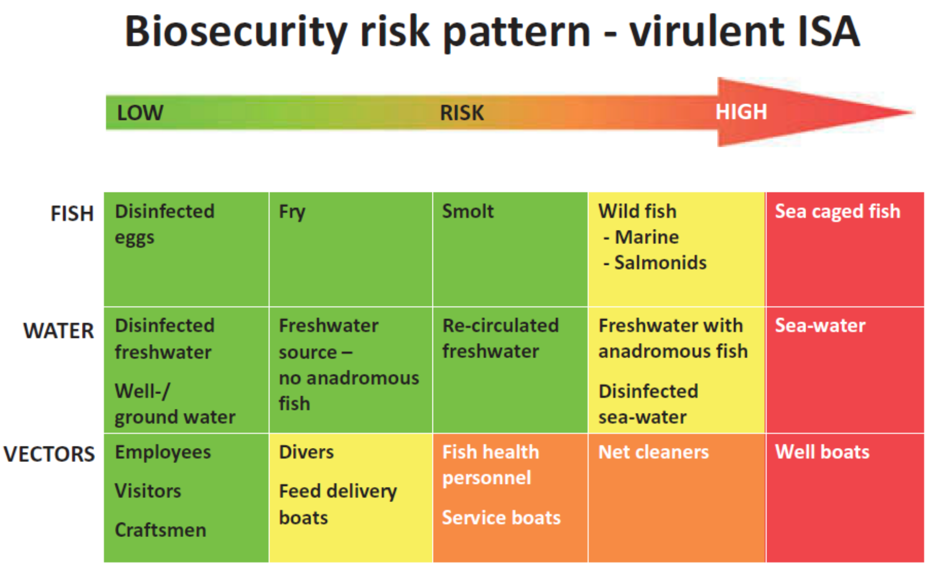

Figure 5. Level of risks for the introduction of virulent infectious salmon anaemia (ISA) virus into an Atlantic salmon production site. Lowest risk is to the left (green), increasing toward the right (red). (Lillehaug et al., 2015)