Aus dem Department f r Nutztiere und   ffentliches Gesundheitswesen in der Veterin rmedizin

der Veterin rmedizinischen Universit t Wien

Universit tsklinik f r Gefl gel und Fische

Abteilung für Fischgesundheit

(Leitung: Univ.-Prof. Dr. Astrid Holzer)

Biosecurity and Biosafety in Aquaculture

Diplomarbeit

Veterin rmedizinische Universit t Wien

vorgelegt von

Kathrin Mark

Wien, im Juni 2023

Betreuer: Univ.-Prof. Dr. em. Mansour El-Matbouli

Gutachterin: Univ.-Prof. Dr.med.vet. Karin Schwaiger

Table of Contents

1. Abstract

With the economic sector of aquacultural food production becoming more and more important due to rising global population and the need to produce enough resources, the Diploma thesis "Biosecurity in Aquaculture" aims to identify the goals, problems and possible solutions regarding modern day aquacultural systems worldwide. This includes definitions of biosecurity in general as well as specifics for aquaculture, laws and regulations regarding production, trade and biosecurity, a selection of common diseases affecting the most popular cultured species, based on recent literature regarding these topics.

2. Kurzfassung

Da der Wirtschaftszweig der aquakulturellen Nahrungsmittelproduktion aufgrund der steigenden Weltbevölkerung und der Notwendigkeit, genügend Ressourcen zu produzieren, immer wichtiger wird, zielt die Diplomarbeit "Biosicherheit in der Aquakultur" darauf ab, die Ziele, Probleme und möglichen Lösungen in Bezug auf moderne Aquakultursysteme weltweit aufzuzeigen. Dazu gehören, basierend auf aktueller Literatur zu folgenden Themen: Definitionen von Biosicherheit im Allgemeinen und für die Aquakultur im Besonderen, Gesetze und Verordnungen zu Produktion, Handel und Biosicherheit, als auch eine Auswahl häufiger Krankheiten, die die gängigsten Zuchtarten betreffen.

3. Introduction

The constant growth of the world population is confronting global food production with new problems, especially when considering it reaching up to at least nine billion people by 2050. Concurrently, global food production will need to rise by an estimated 70% of its present state (Colgrave et al., 2021). However, harvests from wild capture are thought to stabilize at current levels, that is why focusing on alternative food production such as aquaculture becomes more and more important (Rice & Garcia, 2011a; Håstein et al., 2008).

The economic branch of aquaculture food production has been rapidly evolving globally since the 1980s due to an increasing world population on the one hand and a decrease of the global fish population because of overfishing and ecological destruction, respectively habitat loss on the other hand. Therefore, the main goal of aquaculture is to close the gap between demand and accessibility for food. (Colgrave et al., 2021; Obosi & Agbeja, 2015; Peeler & Ernst, 2019; Subasinghe et al., 2019; Xiang, 2015).

The massive growth of aquaculture in different countries leads to various issues regarding national and international restrictions and guidelines, biosecurity and trading as well as animal health. The most crucial problems are lack of information about laws and regulations, absent biosecurity measures, low compliance with farmers and in addition, rise of antibiotic resistance in farmed animals. (Opiyo et al., 2018a; Subasinghe et al., 2019a)

2. Aquaculture

2.1. Definition of Aquaculture

Another term for aquaculture is aquatic agriculture and it is most commonly known for global fish production. Besides food production there are numerous further aspects to aquaculture such as products which are not meant for human consumption, e.g. clothing, pearls and ingredients for skincare products.

In order to maximize the outcome, parameters such as water temperature, light and population size are manipulated. (Lucas, 2015)

Furthermore, aquaculture is an important tool for species conservation as it is possible to breed endangered species in a controlled environment. When the animals have reached a critical size, they can be released into wild natural populations and contribute to conserving their species. (Leibniz-Institut für Gewässerökologie und Binnenfischerei, 2022)

2.2. Aquacultural Systems

Due to the various production lines and cultivated species in aquaculture, there is a huge number of different aquaculture systems present. The classification of these systems is based upon the following four criteria: type of culture structure, water exchange system, intensity of culture and fish farming method (Soltan, 2016).

The terms “open”, “semi-open”, “semi- closed” and “closed” are used to describe the level of animal movement and water flow possibility. (Osborn & Henry, 2019a)

The only type of system, which can be fully monitored and controlled, is the closed system. Here it is possible to set up quarantine measures, and the water used for the tanks is filtered mechanically or biologically. (Australian Aquatic Veterinary Emergency Plan, AQUAVETPLAN Enterprise Manual Version 2.0, 2015 National Biosecurity Committee, 2015)

2.3. Main producers of aquaculture

In 2020, 87,5 million tons of fish and other seafood were produced in aquaculture systems worldwide (Leibniz Institut für Gewässerökologie und Binnenfischerei, 2022).

2.3.1. China

China is by far the world's biggest producer in aquaculture, with a global production rate of nearly 57% in fish and other seafood and 60% in algae. The main source of production in China are fisheries in the marine sector as well as inland. The four most important fishing sites, classified from most productive to least, are East China Sea fishery zone, South China Sea fishery zone, Yellow Sea fishery zone, and Bohai fishery zone.
From the over 3000 marine species being in the Chinese waters, 150 are commercially important. Commercial fishing, including cuttlefish, sea eel, crabs, sea cucumbers, squids and jellyfish target 100 of them (FAO, 2018).

2.3.2. India

Another big producer in aquaculture is India, which focuses on marine fisheries, freshwater- and brackish-water aquaculture. The main species produced in freshwater aquaculture are cyprinids, making up for over 80% of farmed fish as well as fresh water prawns.
Marine fisheries mainly concentrate on Clupeiformes and marine shrimp, whereat shrimp is most important for its export potential. Shrimp is also produced in brackish-water aquaculture, representing over 60% of India's shrimp export (Fishery Country Profile, Food and Agriculture Organization of the United Nations FID/CP/IND, 2006).

2.3.3. The United States of America

With fisheries all over the coastal areas and in the US Exclusive Economic Zone (EEC) as well as rivers and lakes throughout the country, there is a high level of diversity and size of the harvest sector.

The main fisheries by region are:

Northeast region: mixed-species groundfish fishery, lobster and scallops. Nearly all crustaceans and bivalves are fully exploited, therefore Fishery Management Plans (FMPs) are put into effect to rebuild and restore stocks. Out of 47 stocks, 18 are overexploited and under FMPs, in addition, there are three stocks which are not under an FMP.

Southeast region: contains the Gulf of Mexico, the US Southeast Atlantic, and the Caribbean Sea. The main species of this region are sharks, reef fish and shrimp.
There are 22 stocks which are overfished, including a variety of groupers, snappers, tunas and sharks.

Alaska region: the most important species include salmon, herring and crabs. There are two overfished stocks, which are both crabs.

Western Pacific Region: this region stretches across the central and western Pacific and includes the Hawaiian Islands and the US- affiliated islands of American Samoa, Guam, and the Northern Marianas.
Fisheries target migratory stocks like tunas, sharks, swordfish and lobsters.

Pacific coast region: the main species include salmon, halibut and groundfish. Eight stocks are overfished, all of them are groundfish (Fisher Food and Agriculture Organization of the United Nations FID/CP/USA, 2005).

2.3.4. Australia

In Australia, aquaculture is the country's fastest growing industry, although not comparable to the big producers like China and India. Production ranges from rock lobster, southern bluefin tuna and abalone to scallops, shrimps and prawns.

While shrimp fisheries dominate in the northern areas of Queensland bordering the Pacific Ocean, the temperate areas of New South Wales, Victoria, Tasmania and South Australia, are dominated by abalone and rock lobsters.

Western Australia, with its large Indian Ocean sea area is the greatest producer of rock lobster and shrimp in Australia.

The majority of aquaculture production is exported, especially bluefin tuna meeting a high demand in Japan (Food and Agriculture Organization of the United Nations, 2003).

2.3.5. European Union

The European Union (EU) plays a minor role in aquaculture production with Spain and France being the main producers. The top species, which are produced are mussels, salmonids and cyprinids, although the EU still highly depends on importing aquaculture products.
In France, the consumption of aquatic products in kg/capita/year is one of the highest in the EU, resulting in the need to import mainly salmon, shrimp, cod, hake, haddock and tuna. French fisheries target clupeiformes, mackerels and tuna in the Mediterranean Sea.
Spanish aquaculture mainly produces mussels, followed by cyprinids and salmonids. Furthermore, the spanish fleet is the third-largest in the EU, producing primarily tunas (FAO, 2005, 2014; Leibniz Institut für Gewässerökologie und Binnenfischerei, 2022).

2.4. Species produced in Aquaculture

One half of aquaculture production is fish, especially carp and carp-related species. Further species produced include crustacea, molluscs, echinoderms, bivalves and seaweed respectively algae.

Although there is an enormous number of aquatic species present, only a fraction of species are dominating the sector of aquaculture. Freshwater aquaculture is dominated by 24 species groups which represent nearly 79% of global production. The top species are Ctenopharyngodon idellus, Hypophthalmichthys molitrix, Oreochromis niloticus, Cyprinus carpio, Catla catla, Hypophthalmichthys nobilis, Carassius spp., Labeo rohita and Pangasianodon hypophthalmus, each making up for over 5% of global production.

In saltwater and brackish water, 22 species groups make up 76% of global production, led by Salmo salar and Chanos chanos, representing 32,6% and 14%.

Production of crustaceans is dominated by Litopenaeus vannamei, solely accounting for 51,7% of global production.

Molluscs are dominated by Crassostrea spp. and Ruditapes phlippinarum and algae are dominated by Saccharina japonica (Leibniz Institut für Gewässerökologie und Binnenfischerei, 2022).

2.5. A Selection of Relevant Diseases in Aquaculture

With keeping a huge number of animals in confined settings, spreading of diseases and pathogens is more common and poses a huge threat to populations in aquaculture, often resulting in death of affected animals and therefore production loss.

2.5.1. Parasitic Diseases

2.5.1.1. Eimeria spp. - Coccidiosis

Eimeria spp. is a protozoan endoparasite which enters fish orally through ingestion of sporulated oocytes or infected tubificid worms, which serve as vectors.
There are two different types of coccidiosis – the diffuse form and the nodular form. While the diffuse form appears in all seasons and is caused by *Goussia carpelli*, the nodular form only appears in spring and is caused by *Goussia subepithelialis* (Andrews, 2022; Molnar, 1989).
Clinical symptoms include animals laying on the pond bottom with hollow eyes as well as debilitation, a thin body with a large head, oedema of abdominal membranes and intestinal wall and yellowish mucus exuded.
Treatment includes disinfection and drying of ponds as well as administration of Furazolidone through feed (Peteri A., 2005).

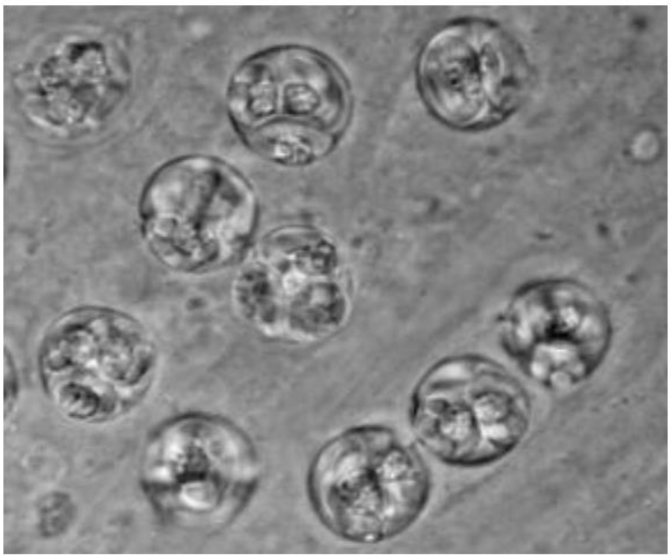

Figure 1. Oocysts of Goussia carpelli in the intestines of common carp (Molnar, 1989)

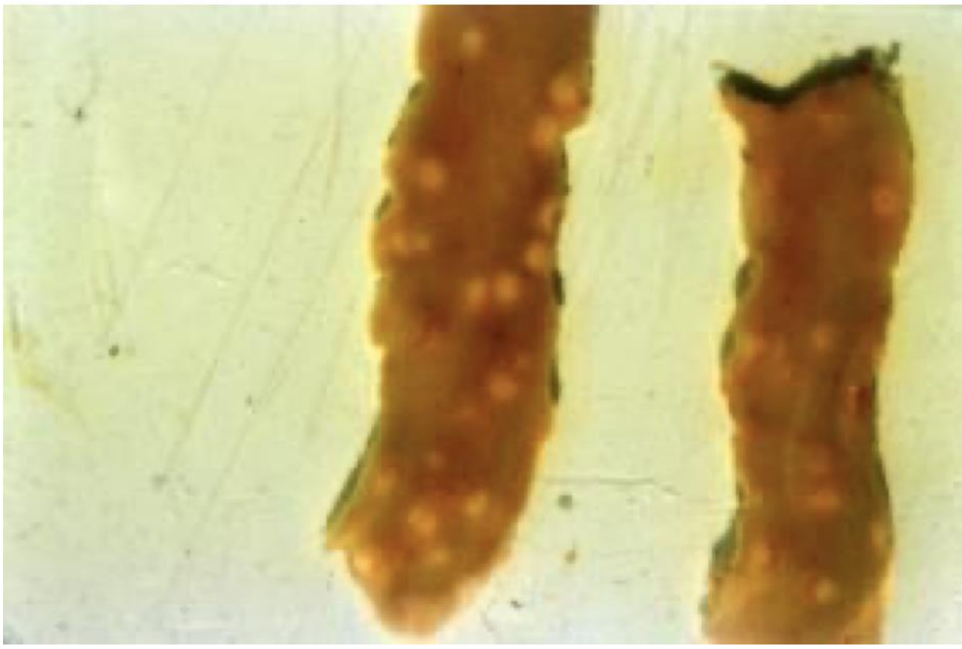

Figure 2. Nodular lesions in the intestine of common carp caused by Goussia subepithelialis (Molnar, 1989)

2.5.1.2. Sealice - Lepeophtheirus salmonis and Caligus elongatus

An infection with sealice results in reduced growth, loss of scales, secondary infections through skin damage and in extreme cases, death.
Treatment of sealice includes Paraciticides either in bath e.g. Azamethiphos, Cypermethrin and Hydrogen peroxide or in feed, e.g. Emamectin or Teflubenzuron (M. Jones, 2004).

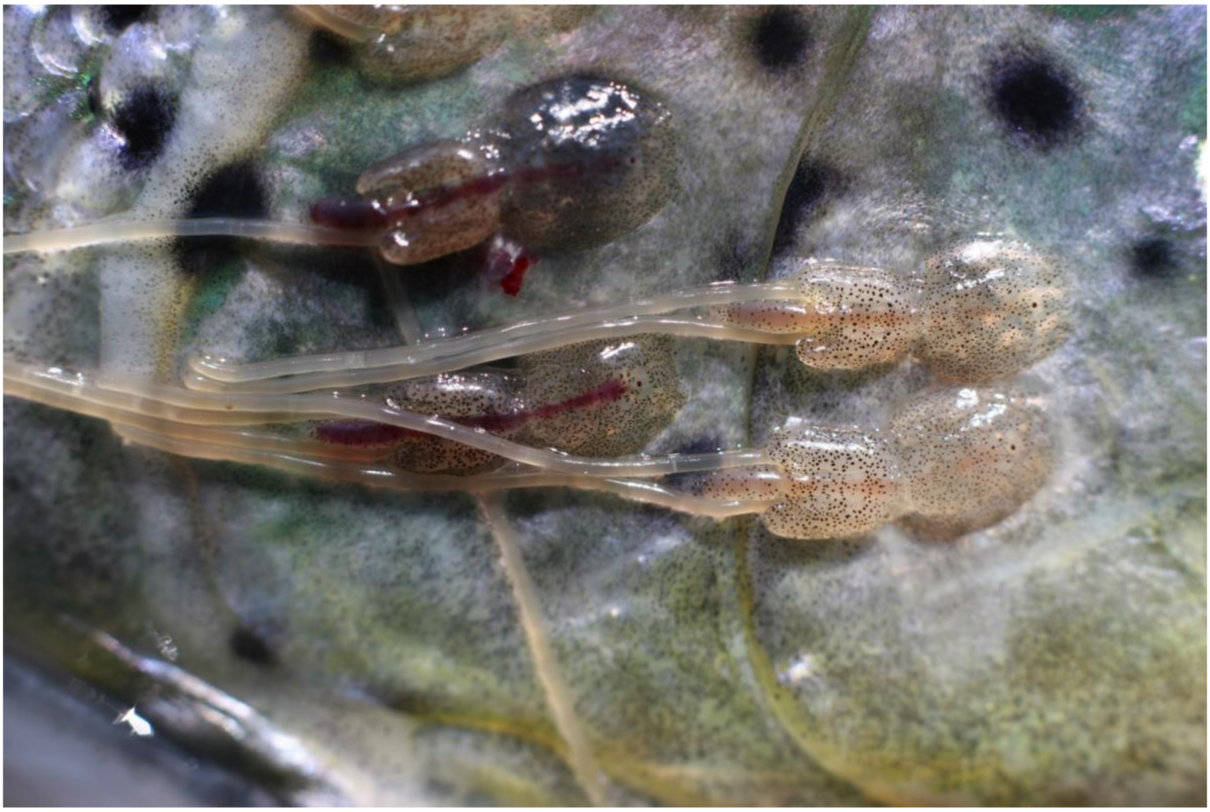

Figure 3. Adult female salmon sealice (Lepeophtheirus salmonis) (Nilsen & Hamre, 2021)

2.5.2. Bacterial Diseases

2.5.2.1. Aeromonas hydrophila - Carp erythrodermatitis, Ulcer Disease

This disease is also called the chronic or ulcerative form of “Infectious dropsy of carp”.
Infected carp can show small spherical nodules on their fins, protruding scales, exophthalmus, hemorrhagic gills, and ulcers with a jagged rim.
Treatment includes avoiding stress and administration of antibiotics in feed or as injections. Furthermore, it is possible to vaccinate animals as prophylactic treatment (Peteri A., 2005).

Figure 4. Koi displaying ulcerative dermatitis showing cutaneous ulcers, exposing the underlying muscles (Roberts et al., 2009)

2.5.2.2. Flavobacterium columnaris - Columnaris Disease in carps

When water temperature rises above 20°C and the fish are under stress, ammonia intoxication will occur and damage the gills, preparing a gate of entry for the bacteria.

Affected fish show grey-white spots, surrounded by a zone with reddish tinge on the head, gills, skin and fins as well as destroyed membranes between fin rays.

Treatment is possible with Benzalkonium Chloride, Copper Sulphate or antibiotics such as Furazolidone, Neomycin, Oxytetracycline and Terramycin (Declercq et al., 2013).

Figure 5. Yellowish-white degenerative lesions in gills of Carassius auratus (Declercq et al., 2013)

2.5.2.3. Piscirickettsia salmonis - Salmon Rickettsial Disease (SRS)

The bacteria enters the host through gills, skin and intestinal epithelium. Infected animals appear darker and lethargic, swimming uncoordinated or near the surface. Further symptoms include focal skin lesions, raised scales, nodules or ulcers. It is also possible that affected fish don't show any signs of infection (S. R. M. Jones, 2019).

Treatment includes oral administration of antibiotics. Due to emerging resistances, Quinolones such as Oxolinic Acid and Flumequine, have proven effective (Almendras & Fuentealba, 1997).

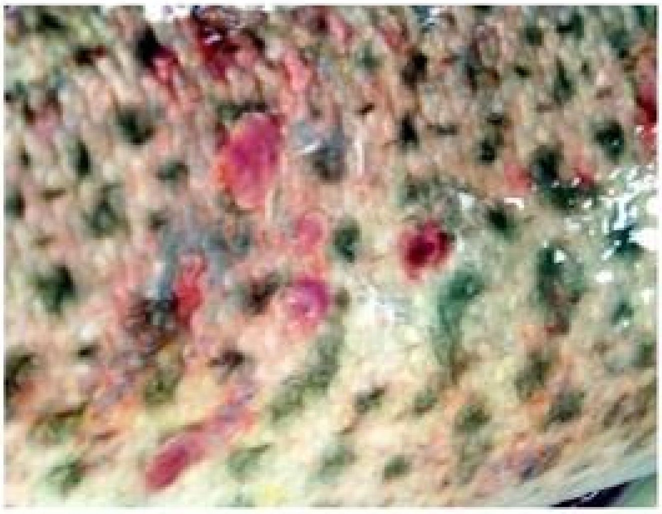

Figure 6. Skin lesions and hemorrhages caused by Piscirickettsia salmonis (Kipp et al., 2018)

2.5.3. Viral Diseases

2.5.3.1. Rhabdovirus carpio - Spring viraemia of carp (SVC), acute/ascitic form

When the water temperature rises in spring and the animals experience stress, the disease becomes manifest.

Symptoms include erratic swimming at first, later lethargy. Furthermore, enteritis, oedema, exophthalmia, pale gills and hemorrhages in skin.

Treatment includes elimination of vectors, such as blood sucking parasites and caution when introducing new animals to the population, e.g. by putting them into quarantine first (Peteri A., 2005).

Figure 7. Exophthalmia and petechial hemorrhages in Cyprinus carpio infected with SVC (Lewbart & Shivappa., 2016)

2.5.3.2. Viral Haemorrhagic Septicaemia Virus - Viral Haemorrhagic Septicaemia

This virus belongs to the family of Rhabdoviruses, affecting a wide range of fish species including salmoniformes, clupeiformes, perciformes, cypriniformes, etc. It is transmitted via urine and reproductive fluids.

Common symptoms include bulging eyes and, in some cases, bleeding eyes, pale gills, swollen abdomen and lethargy.

There is no treatment available, the implementation of a vaccine is intended. Eliminating stress factors such as poor water quality, high population density and frequent handling can reduce mortality (Wahli, 2013)(*Viral Haemorrhagic Septicaemia*, n.d.).

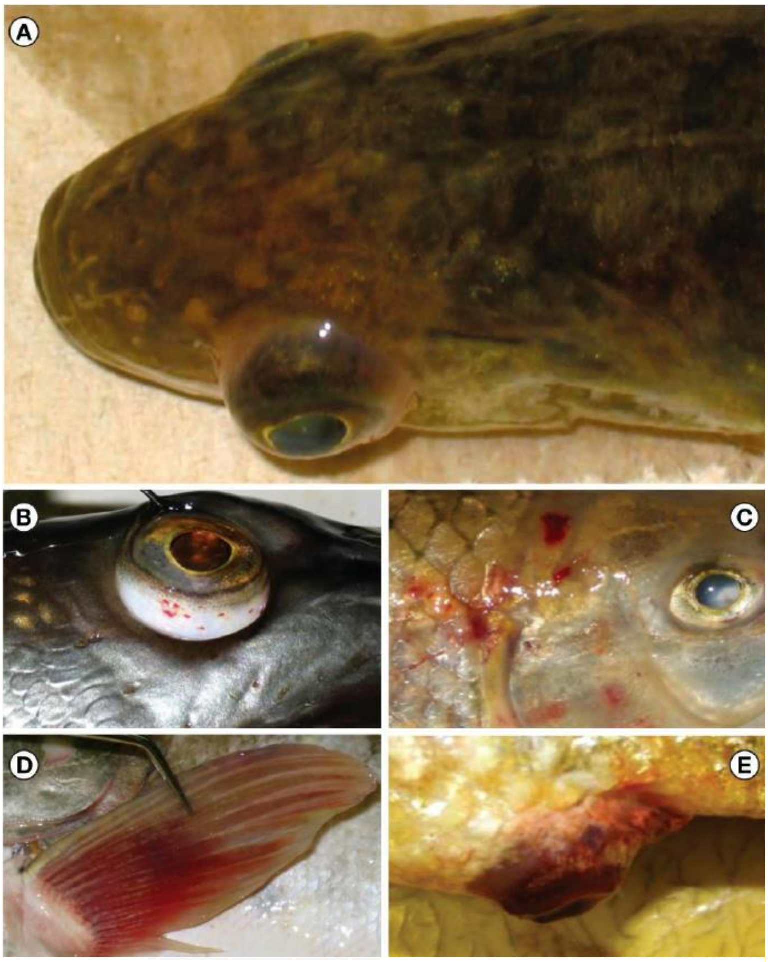

Figure 8. Clinical signs of an infection with Haemorrhagic Septicaemia Virus including exophthalmia (A), hemorrhages around the eye (B), on the skin (C) and on the fins (D) as well as a protruded and hemorrhagic vent (Faisal et al., 2012)

2.5.3.3. Infectious Spleen and Kidney Necrosis Virus – Infectious Spleen and Kidney Necrosis

This disease is caused by Megalocytivirus, causing symptomatic infections as well as asymptomatic ones. Common symptoms include anorexia, paleness, uncoordinated swimming patterns, petechial hemorrhages, swollen gills, skin ulcerations.

There is no treatment available, a crucial element to prevent the introduction of the pathogen into the population is implementing quarantine routines for newly imported animals (Crim, 2020; Jung-Schroers et al., 2016).

Figure 9. Paleness and petechial hemorrhages in a zebrafish infected with Infectious Spleen and Kidney Necrosis Virus (Crim, 2020)

2.5.3.4. Yellow-Head Virus - Yellow Head Disease

An infection leads to cellular necrosis, affecting a wide variety of organs and systems, resulting in a pale-yellow cephalothorax due to discoloration of hepatopankreas and gills. Affected species are penaeid shrimp species, palaemonid shrimp species and krill.

Treatment is not available, disinfection plays a key role in preventing the introduction into a population (Seibert & Pinto, 2012; Walker & Sittidilokratna N., 2008).

Figure 10. Yellow-pale discoloration of the cephalothorax in the left group (A) and gills in Penaeus monodo (Lee et al., 2022)

2.5.3.5. Carp edema virus (CEDV) - Carp edema, Koi sleepy disease

CEDV is a poxvirus affecting cyprinids and poses a huge threat to populations in aquaculture. Infected animals show lethargy, lying motionless on the bottom of the tank, resulting from gill necrosis as well as anorexia, enophthalmia and ulcerations around the mouth and the base of the fins. Juvenile animals tend to show skin hemorrhages, edema and an overproduction of mucus on skin and gills.

Currently, there is no therapy available, the main goal is to implement biosecurity measures to prevent the pathogen from entering the populations (Way et al., 2017).

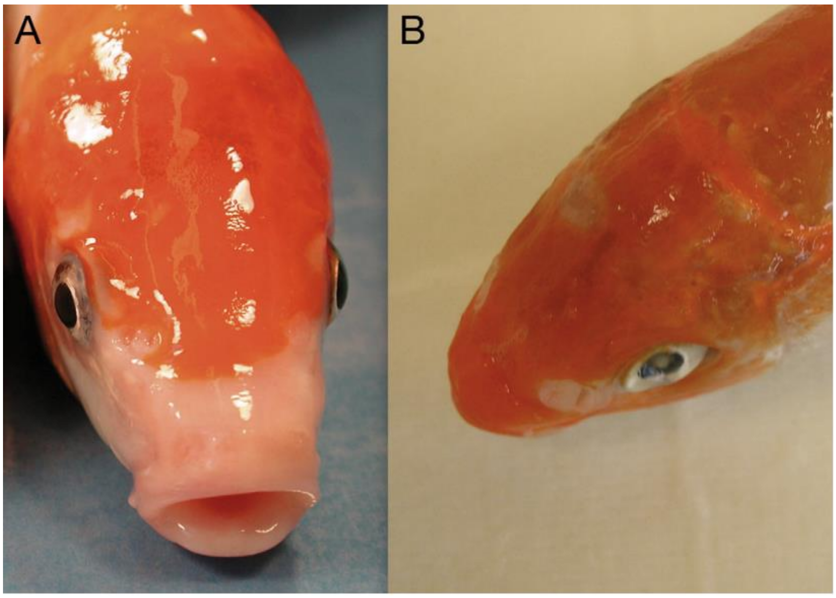

Figure 11. Comparison of normophthalmia (A) and enophthalmia (B) in Cyprinus caprio, occurring as a clinical sign of an infection with CEDV (Way et al., 2017)

2.5.4. Fungal Diseases

2.5.4.1. Saprolegnia spp. - Saprolegniosis

This fungal infection starts with biflagellate zoospores that swim and attach onto the fish. The fungal hyphae penetrate only the epidermis and dermis, causing white fungal colonies on the body surface as well as wounded areas or ulcers. When left untreated, the animals die from osmoregulatory problems because of the tissue damage (M. Jones, 2004).

Figure 12.: Skin lesions on Salmo salar (A) and Onchorhynchus mykiss (B) caused by Saprolegnia spp. Destroyed eggs of Salmo salar due to infection with Saprolegnia spp. (C) (Wiencke, 2011)

2.5.4.2. Aspergillus flavus - Black Gill Disease

This fungal infection affects all life stages of shrimp, though older ones seem to be more vulnerable.

Common symptoms include black gills and white coloration of the outer layer of the eyeball. In addition, ulcerated melanized lesions can occur.

There is no treatment available, preventing the introduction of the disease is the key, e.g. through thorough disinfection between crops, avoiding accumulation of organic matter on the bottom of the tank and controlling the population size.

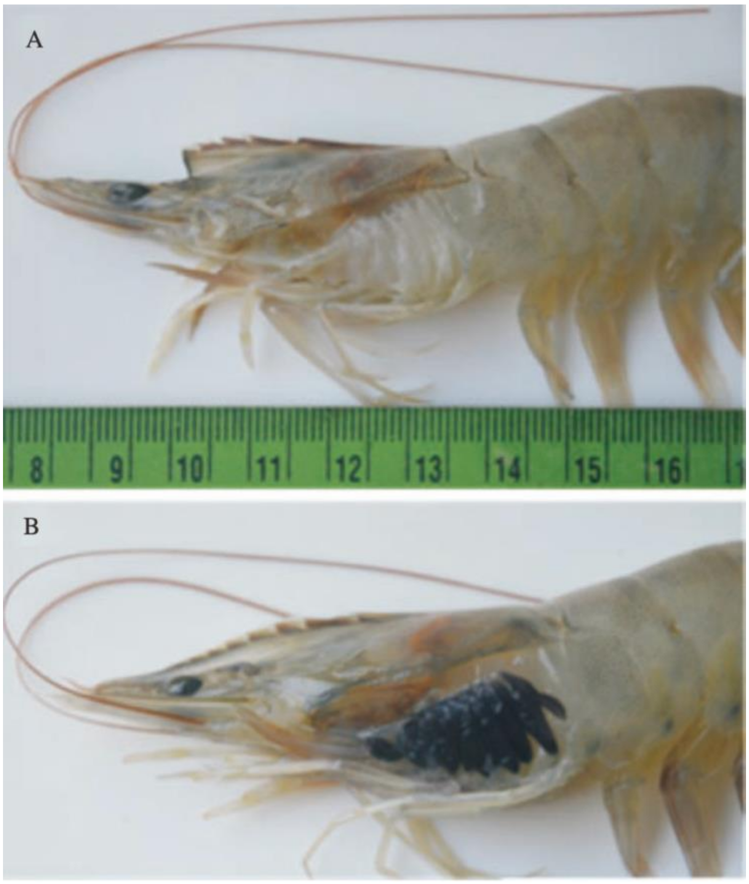

Figure 13. Comparison of healthy gills (A) and infected gills (B) showing black discoloration in Litopenaeus vannamei. (Dewangan et al., 2015)

3. Biosecurity

3.1. Definition of Biosecurity

Biosecurity is a term used to describe the measures and practices put in place to protect the health and well-being of animals, plants, and the environment.
In aquaculture, biosecurity refers to the specific measures and practices put in place to protect the health and well-being of aquatic animals and the environment in which they are raised. This can include measures such as implementing quarantine procedures, controlling the movement of animals and equipment, and implementing proper sanitation practices. (Assefa & Abunna, 2018; B. C. Oidtmann, Thrush, et al., 2011; Osborn & Henry, 2019; Håstein et al., 2008; Murray & Peeler, 2005)

3.2. Relevance of Biosecurity in Aquaculture

Due to increasing demand of aquacultural products, it is important to maximize the outcome, thus to minimize losses through disease and other quality reductions (Murray & Peeler, 2005).

Unfortunately, high loss rates can be found throughout the aquaculture sector for various reasons. The most common problem concomitant with high loss rates is spreading of pathogens and diseases, which can lead to animal death or reduction of quality. Pathogens can be transmitted via so called “vectors” such as carrier organisms, people or equipment Click or tap here to enter text. (Anderson et al., 2014).

Therefore, it is important to efficiently reduce the introduction of pathogens to aquacultural populations as well as reducing the use of prophylactics, including antibiotics and instead focusing on vaccination and using operant biosecurity and biosafety programs (Assefa & Abunna, 2018; Opiyo et al., 2018).

The main goal of a Biosecurity program is to reach and maintain disease freedom both in individual facilities and nationally as well as to anticipate the establishment of pathogens into the environment by achieving so-called Specific Pathogen Free (SPF) animal populations as well as to detect existing diseases (Murray et al., 2022; Osborn & Henry, 2019).

Preventing diseases does not only affect livestock and thus tradability of the products as well e.g., if the facility is not disease-free, the product cannot be sold or has to be sold at a lower price (Palić et al., 2015).

There are four key areas for contamination control to minimize an infection within the population, which are water quality, water exchange, tools and staff and lastly, carriers and mobile tools (Oidtmann & Crane, et al., 2011).

Monitoring of the livestock is very important despite taking all those biosecurity measures to distinguish possible pathological processes within the population. Therefore, it is indispensable to frequently keep track of water quality, livestock appearance and behavior, morbidity and mortality as well as performing general system maintenance.

3.3. Laws and Regulations regarding Biosecurity in Aquaculture

Laws and regulations regarding biosecurity in aquaculture vary by country, but generally include guidelines for disease prevention and control, sanitation, and animal welfare. There are several different guidelines and regulations present throughout the world, for example the Australian AQUAPLAN, respectively AQUAVETPLAN, as one of the first strategies to include Biosecurity measures into legislation since 2003. It is the result of a collaboration between government, veterinarians and aquaculture producers and defines practical and economical strategies for strengthening biosecurity along the borders and inland. Furthermore, the AQUAVETPLAN includes instructions to preserve the advantages of aquaculture while conforming with the regulations of the Australian Biosecurity Compliance Strategy. One very big challenge to achieve this goal was to support biosecurity on company-level to make sure that the applied biosecurity programs were practically and economically viable (Australian Aquatic Veterinary Emergency Plan AQUAVETPLAN Enterprise Manual Version 2.0, 2015 National Biosecurity Committee, 2015).

Another example for guidelines regarding biosecurity is the American-Canadian Aquatic Animal Health Program from 2009, which includes recommendations for disease management, diagnostics, monitoring, disinfection and quarantine to minimize the possible consequences in case of an outbreak (Håstein et al., 2008).

Last named is the so-called SPS-Agreement (Sanitary and Phytosanitary Measures Agreement) by WTO. It contains global biosecurity strategies for direct as well as indirect health measurements regarding international trading which apply on every member of the EU as EU Directive 2006/88/EC (Håstein et al., 2008). The objective of this agreement is to avoid trade-protectionism by providing equal regulations for every member. However, one issue of this agreement is missing information on how to reach these equal levels of biosecurity which leads to inconsistent biosecurity levels in different countries. Furthermore, interpreting these regulations is partially left to regional and national governments (Palić et al., 2015). Furthermore, EU Directive 2006/88/EC aims to classify aquaculture facilities for their individual risk of acquiring or transmitting diseases and pathogens. Each farm is assessed and classified into risk level high, medium or low. Based on these risk levels, the frequency of farm inspections is determined (Wahli, 2013).

4. Discussion

The constant growth of the world population is confronting global food production with new problems, especially when considering it reaching up to at least nine billion people by 2050. Concurrently, global food production will need to rise by an estimated 70% of its present state (Colgrave et al., 2021). However, harvests from wild capture are thought to stabilize at current levels, that is why focusing on alternative food production such as aquaculture becomes more and more important (Rice & Garcia, 2011).

The economic branch of aquacultural food production has been rapidly evolving globally since the 1980s due to an increasing world population on the one hand and a decrease of the global fish population because of overfishing and ecological destruction, respectively habitat loss on the other hand. Therefore, the main goal of aquaculture is to close the gap between demand and accessibility for food (Colgrave et al., 2021; Obosi & Agbeja, 2015; Peeler & Ernst, 2019; Subasinghe et al., 2019; Xiang, 2015).

The massive growth of aquaculture in different countries leads to various issues regarding national and international restrictions and guidelines, biosecurity, and trading as well as animal health. The most crucial problems are lack of information about laws and regulations, absent biosecurity measures, low compliance with farmers, and in addition, rise of antibiotic resistance in farmed animals (Opiyo et al., 2018; Subasinghe et al., 2019). Another challenge in implementing effective biosecurity measures in aquaculture is the lack of awareness and understanding of the regulations and guidelines that are in place, resulting in poor compliance among farmers and an increased risk of disease outbreaks (Obosi & Agbeja, 2015). In order to address this issue, there is a need for increased education and training for aquaculture farmers, as well as greater enforcement of biosecurity regulations by government agencies (Opiyo et al., 2018).

The importance of biosecurity in aquaculture cannot be overstated. Not only does it protect the health of the aquatic animals being farmed, but it also ensures the safety of the food that is produced, and the economic success of the industry (Christison, 2019). Biosecurity measures are necessary at all stages of production, including disease detection, control and eradication, as well as the implementation of quarantine procedures to prevent the introduction and spread of pathogens (Oidtmann et al., 2013; Oidtmann & Thrush, et al., 2011).

An important aspect of biosecurity in aquaculture is the use of disinfection and cleaning methods in order to prevent the spreading or introduction of pathogens or invasive non-native species (INNS) into populations (Anderson et al., 2014).
These can include physical methods such as heat treatment and UV radiation, as well as chemical methods such as chlorine and hydrogen peroxide (Aquaculture-Biosecurity The Importance of Biosecurity and Disinfection in Aquaculture, n.d.). It is important to note that the use of disinfectants must be done with care, as wrong use or contamination of disinfectants can lead to the development of antibiotic resistance in aquatic animals (Moore et al., 2010; Tidbury et al., 2018).

Another important aspect of biosecurity is the implementation of risk-based surveillance methods. These methods involve the identification and assessment of potential biosecurity risks, and the development of strategies to mitigate or manage those risks (Oidtmann et al., 2013). This can include regular monitoring of water quality, animal movements, regular health checks of the aquatic animals, and implementing strict biosecurity protocols for visitors and equipment entering the facility (Osborn & Henry, 2019; Wahli, 2013).
It is crucial that biosecurity measures are implemented in all stages of the aquaculture production process to ensure the health and well-being of the animals and the safety of the final product for consumers. This includes measures such as implementing quarantine protocols, using closed systems for production, and regular monitoring and testing for disease. In addition, it is important for government officials, veterinarians, and producers to work together to establish and implement effective biosecurity plans.

The International Association for Aquatic Animal Medicine and Biosecurity (IAVBC) offer an example of a standardized biosecurity program for aquaculture. This program includes steps such as defining an epidemiological unit (EpiUnit), which consists of a selected population of livestock, and conducting pre-assessment questionnaires to gather information about the facility, including production type, physical and human resources, disease status, perceived risks, and expected goals. Additionally, it is important to evaluate the risks and impacts of specific diseases on the operation and to identify potential vectors for disease transmission.
Each EpiUnit is unique, so the Biosecurity plan needs to be established individually and it is

important to be well informed about the facility, including production type, physical and human resources, disease status, perceived risks and expected goals. The simplest way to gather all this information is through a pre assessment questionnaire. The Center for Food Security and Public Health designed such a document for cattle, and it was adjusted to accommodate for aquaculture facilities as well. The questions are according to Moore et al., 2010 and Palić et al., 2015) as followed:

What diseases are serious hazard potential for my farm/EpiUnit?
Collaboration between producers and veterinarians is the key to identify potentially hazardous diseases for each individual location. Furthermore, the veterinarian has access to information about the situation of relevant or notifiable diseases from regulatory authorities. With all this information, listing all relevant diseases depicts the base for elaborating estimated risks and impacts for every disease.

Is my farm at risk? If so, how much risk and what is the impact of disease on my operation?
EU directive 2006/88/EC and the Aquatic Animal Health Code characterize a number of criteria which are in relation to diseases. Each criterium needs to be evaluated and ranked for risk of production loss, possible spreading to wildlife or regions as well as availability of reliable diagnostic testing.
It is necessary that every EpiUnit is individually evaluated based on its specific situation, e.g. which diseases pose a threat and are most likely to happen. For identifying relevant diseases, risk profiling or semiquantitative methods can be used. Both deliver an objective overview for every individual disease and combining this with disease reports, epidemiological information and specialized knowledge, a distinct fingerprint of the disease is generated.

Where can these hazardous diseases get in or out (if present)?
Vectors are playing a big role in transmitting diseases. For preventing these vectors from entering, leaving or spreading the facility, biosecurity measures need to be taken. There are a number of elements that must be taken into consideration, including understanding of production systems in the farm or EpiUnit, the physical layout and process flow of the operation, the biology of farmed species and at least, pathobiology and epidemiology of the

concerning pathogens or diseases (Palić et al., 2015).
Including a detailed record of operation orders into the biosecurity plan can be used to point out possible ways of pathogen or disease entry/escape.

What can be done to prevent disease entry or escape?
In every step that includes the transfer of biomass, Critical Care Points need to be defined in order to protect the health state of the EpiUnit. In addition to CCPs, critical limits (minimum and maximum) can be defined and work as a monitoring system for establishing and controlling the CCPs.

What should I do if a disease gets in?
Contingency plans are the key to recover fast and with minimum cost and disruption of the affected EpiUnit. The design of such a plan should focus on detecting and controlling the outbreak of a disease. Of course, not every disease can be considered from the beginning, therefore it is important to monitor animal morbidity and mortality. In case of any abnormalities, animals should be isolated and examined to identify any given disease.
Furthermore, a contingency plan needs to include communicating details in the event of an outbreak, all potentially affected parties must be informed about a changing disease status.
Continuing, the definition of areas where a disease can be monitored, and control measures can be executed is essential.
The definition includes:

b1: Infected Zone: infected cases are confirmed; therefore, this zone needs to be in isolation or quarantine. No animals must move out of the EpiUnit, except for moving to the slaughter plant in case of depopulation to reduce the origin of infection. The movement restriction also applies to staff, equipment and vehicles.

b2: Buffer Zone: area between Infected Zone and proven Disease-Free Zone. An important step is to perform diagnostic testing in order to identify further infected cases. In case of any further infections, animal movement may be restricted and if possible, preventative vaccinations can be administered.

b3: Disease-Free Zone: no infected cases should be in this zone. To rule out the possibility of an infection, a dense disease surveillance program must be performed.

Instead of so-called Zoning, it is also possible to perform a compartmentalization. In a compartment, one or more farms are united under a common biosecurity program and management. It contains populations which are suffering from the same disease and must be monitored and controlled and of course accurately documented by an authorized individual. The main goal is to meet the basic biosecurity conditions to enable trading (Australian Aquatic Veterinary Emergency Plan AQUAVETPLAN Enterprise Manual Version 2.0, 2015 National Biosecurity Committee, 2015).

The OIE Aquatic Animal Health Code has specified the requirements for contingency plans on government level, including access to emergency funds for compensating producers, introducing a central decision-making unit to speed up reacting and dealing with an outbreak, adequate resources for implementing the necessary steps and adequate diagnostic laboratory facilities to receive and analyze samples.

For a facility itself, an operations manual should be introduced into the biosecurity plan including all actions, procedures, instructions and control measures in detail, e.g., isolation, quarantine, treatment or emergency vaccinations, depopulation if necessary and proper disposal. It is crucial to understand that the disposal of infected biological material bears a great risk of spreading a disease. Therefore, processing plants need to have an efficient decontamination routine, also including knowledge of specific pathogen-transmissions.

In the case of an outbreak, the source and entry should be determined through an epidemiological investigation to improve biosecurity levels at these sites.

Are there any of these diseases on the farm?
A veterinarian needs to perform clinical evaluation and disease testing according to the diseases listed in the facility's biosecurity plan. This includes a visit of the EpiUnit, clinical examination, necropsy and access to site records and historic records provided by the producer.
Necropsy is performed in order to receive samples for diagnostic testing. These samples can be processed in different ways, either in the facility's laboratory, if possible, or in a third- party laboratory. The decision which laboratory to choose depends on the facility's biosecurity plan, desired level of certification, potential contractual commitment and regulatory requirements. The OIE provides a list of reference laboratories for aquatic animal diseases as well as a list of available and validated tests for specific disease diagnostics (OIE 2015b). For further consultation, a veterinary epidemiologist can be employed to determine the number of animals needed for testing and sampling frequency.

How do I continue to monitor disease absence/presence?
The most efficient way to ensure optimum disease surveillance is frequent sampling for diseases, especially in the initial years of establishing a biosecurity program in the EpiUnit. In case the biosecurity program is efficient, the Facility can also reach a state of stable disease freedom where no surveillance is needed as long as the biosecurity situation does not change.

What information should I keep, and in what form?
Biosecurity plans require records in written form; however, visual records can be useful as well to provide evidence of past events.
The main problem with written records is the risk of misinterpretation when associated metadata is missing. The rule of thumb is therefore: the more records of an event are available and the more time they cover, the more useful the information.
Records need to be updated and accurate to predict events that could happen in the future.
Of course, not all information is useful for the facility. Therefore, it is beneficial to study the aims of the biosecurity plan, as these will show which records are important to keep and in which form.

How do I get third-party recognition of disease freedom?
Certificates are the key to broad recognition. While an SPF-certificate offers the highest number of advantages, the compliance may suffer under regulatory complexity and frequent diagnostic testing. In these cases, there are other certificates to obtain e.g., zoo-sanitary certificates such as “Certificate of Veterinary Inspection”. By receiving and maintaining such certificates and especially maintaining biosecurity, regulatory burden for producers and governmental agencies decreases over time and thus increases compliance as well as aquaculture production.

Hazard Analysis and Critical Control Points (HACCP) is another important tool for ensuring biosecurity in aquaculture. This system is based on identifying and controlling potential hazards in the production process, such as disease outbreaks, and implementing measures to prevent them. This includes regular monitoring and testing, implementing protocols for dealing with disease outbreaks, and training staff on biosecurity measures (Håstein et al., 2008).

In summary, biosecurity is crucial for ensuring the health and well-being of farmed aquatic animals and the safety of the final product for consumers. This includes implementing quarantine protocols, using closed systems for production, and regular monitoring and testing for disease as well as daily monitoring for morbidity and mortality (~~K. N.~~ Murray et al., 2016). Effective biosecurity plans should be established and implemented by government officials, veterinarians, and producers working together, and tools such as HACCP can also be used to identify and control potential hazards in the production process. With the increasing importance of aquaculture in global food production, it is crucial that biosecurity measures are implemented to ensure the sustainability and success of the industry.
Biosecurity is essential for protecting the health of aquatic animals, ensuring the safety of the food produced, and supporting the economic success of the industry. Effective biosecurity measures must be implemented at all stages of production, and should include the use of disinfection methods, risk-based surveillance, and regular monitoring of water quality. Additionally, education and training for aquaculture farmers, and greater enforcement of biosecurity regulations by government agencies, can help to improve compliance and reduce the risk of disease outbreaks. Furthermore, implementing a HACCP program can be an additional solution for ensuring the safety of the final products and maintaining consumer trust.

With these measures in place, the aquaculture industry can continue to grow and provide a sustainable source of protein for the increasing global population.

5. Conclusion

In conclusion, biosecurity is a crucial aspect of the aquaculture industry. It is essential for protecting the health of aquatic animals, ensuring the safety of the food produced, and supporting the economic success of the industry. Effective biosecurity measures must be implemented at all stages of production, and should include the use of disinfection methods, risk-based surveillance, and regular monitoring of water quality. Additionally, education and training for aquaculture farmers, and greater enforcement of biosecurity regulations by government agencies, can help to improve compliance and reduce the risk of disease outbreaks.

Biosecurity in aquaculture is a complex and multifaceted issue that requires a comprehensive and coordinated approach. The implementation of biosecurity measures such as quarantine, disinfection, and proper sanitation practices, as well as the use of HACCP, are key strategies for addressing the challenges of biosecurity in aquaculture. The importance of education, training, and collaboration between producers, veterinarians, and government officials is also crucial in order to build a sustainable and profitable aquaculture industry. Additionally, the use of risk assessment, management strategies, biosecurity best practices, sustainable practices, international cooperation, research and development, and social and economic considerations are all important for ensuring the biosecurity of the aquaculture industry.

The future of aquaculture looks promising, with an increasing demand for seafood and a growing recognition of the potential for aquaculture to provide sustainable protein sources. However, in order for the industry to continue to grow and thrive, it is essential that effective biosecurity measures are implemented and maintained. This includes not only the use of disinfection methods and risk-based surveillance, but also the development of comprehensive biosecurity plans that take into account the unique needs and risks of each individual facility. Additionally, there is a need for increased education and training for aquaculture farmers, as well as greater enforcement of biosecurity regulations by government agencies. (Osborn & Henry, 2019)

Furthermore, the advancement of technology and research in the field of aquaculture biosecurity is expected to play a key role in addressing current challenges. For example, the use of genetic markers and vaccination techniques can help to create disease-resistant fish populations and to prevent the spread of diseases (Osborn & Henry, 2019). Additionally, developments in biosecurity technology such as the use of sensors and automation can help to enhance disease detection and monitoring.

6. Table of Figures

7. References

Australian Aquatic Veterinary Emergency Plan AQUAVETPLAN Enterprise Manual Version 2.0, 2015 National Biosecurity Committee. (2015). www.agriculture.gov.au

Almendras, F. E., & Fuentealba, I. C. (1997). Salmonid rickettsial septicemia caused by Piscirickettsia salm onis : a review. In *DISEASES OF AQUATIC ORGANISMS* (Vol. 29).

Anderson, L. G., White, P. C. L., Stebbing, P. D., Stentiford, G. D., & Dunn, A. M. (2014). Biosecurity and vector behaviour: Evaluating the potential threat posed by anglers and canoeists as pathways for the spread of invasive non-native species and pathogens. *PLoS ONE*, *9*(4). https://doi.org/10.1371/journal.pone.0092788

Andrews, A. (2022). *Overview of Coccidiosis in Animals*. https://www.msdvetmanual.com/digestive-system/coccidiosis/overview-of-coccidiosis-in-animals

Aquaculture-Biosecurity The importance of biosecurity and disinfection in aquaculture. (n.d.).

Assefa, A., & Abunna, F. (2018). Maintenance of Fish Health in Aquaculture: Review of Epidemiological Approaches for Prevention and Control of Infectious Disease of Fish. In *Veterinary Medicine International* (Vol. 2018). Hindawi Limited. https://doi.org/10.1155/2018/5432497

Australian Aquatic Veterinary Emergency Plan AQUAVETPLAN Enterprise Manual Version 2.0, 2015 National Biosecurity Committee. (2015). www.agriculture.gov.au

Christison, K. (2019). Building a sustainable aquaculture industry in South Africa: the role of biosecurity. *Revue Scientifique et Technique (International Office of Epizootics)*, *38*(2), 589–600. https://doi.org/10.20506/rst.38.2.3006

Colgrave, M. L., Dominik, S., Tobin, A. B., Stockmann, R., Simon, C., Howitt, C. A., Belobrajdic, D. P., Paull, C., & Vanhercke, T. (2021a). Perspectives on Future Protein Production. In *Journal of Agricultural and Food Chemistry* (Vol. 69, Issue 50, pp. 15076–15083). American Chemical Society. https://doi.org/10.1021/acs.jafc.1c05989

Crim, M. J. (2020). Viral Diseases. In *The Zebrafish in Biomedical Research* (pp. 509–526). Academic Press.

Declercq, A. M., Haesebrouck, F., van den Broeck, W., Bossier, P., & Decostere, A. (2013b). *Columnaris disease in fish: a review with emphasis on bacterium-host interactions*. http://www.veterinaryresearch.org/content/44/1/27

Dewangan, N. K., Gopalakrishnan, A., Kannan, D., Shettu, N., & Singh, R. R. (2015). Black gill disease of Pacific white leg shrimp (Litopenaeus vannamei) by Aspergillus flavus. *Journal of Coastal Life Medicine*, *3*(10), 761–765. https://doi.org/10.12980/jclm.3.2015j5-70

Faisal, M., Shavalier, M., Kim, R. K., Millard, E. v., Gunn, M. R., Winters, A. D., Schulz, C. A., Eissa, A., Thomas, M. v., Wolgamood, M., Whelan, G. E., & Winton, J. (2012). Spread of the emerging viral hemorrhagic septicemia virus strain, genotype IVb, in Michigan, USA. *Viruses*, *4*(5), 734–760. https://doi.org/10.3390/v4050734

Fao. (n.d.). *FAO Fisheries and Aquaculture Circular SEC/C1182 (En) FIELD GUIDE TO WARMWATER FISH DISEASES IN CENTRAL AND EASTERN EUROPE, THE CAUCASUS AND CENTRAL ASIA*.

FAO. (2005). *PROFIL DE LA PÊCHE PAR PAYS: LA RÉPUBLIQUE FRANÇAISE FISHERY COUNTRY PROFILE Food and Agriculture Organization of the United Nations*.

FAO. (2014, November 17). *© FAO 2023. Fishery and Aquaculture Country Profiles. España, 2011. Country Profile Fact Sheets. Fisheries and Aquaculture Division [online]. Rome.* . https://www.fao.org/fishery/en/facp/esp?lang=es

FAO. (2018). *© FAO 2023. Fishery and Aquaculture Country Profiles. China, 2017. Country Profile Fact Sheets. Fisheries and Aquaculture Division [online]. Rome.* . https://www.fao.org/fishery/en/facp/chn?lang=en

FISHERY COUNTRY PROFILE Food and Agriculture Organization of the United Nations FID/CP/IND. (2006).

FISHERY COUNTRY PROFILE Food and Agriculture Organization of the United Nations FID/CP/USA. (2005).

Food and Agriculture Organization of the United Nations. (2003). *Fishery Country Profile FAO Australia*.

Håstein, T., Binde, M., Hine, M., Johnsen, S., Lillehaug, A., Olesen, N. J., Purvis, N., Scarfe, A. D., & Wright, B. (2008). National biosecurity approaches, plans and programmes in response to diseases in farmed aquatic animals: evolution, effectiveness and the way forward. In *Rev. sci. tech. Off. int. Epiz* (Vol. 27, Issue 1). www.oie.int

Jones, M. (2004). *© FAO 2023. Salmo salar. Cultured Aquatic Species Information Programme.* https://www.fao.org/fishery/en/culturedspecies/salmo_salar/en

Jones, S. R. M. (2019). *Canadian Science Advisory Secretariat (CSAS) Characterization of Piscirickettsia salmonis and salmonid rickettsial septicaemia to inform pathogen transfer risk assessments in British Columbia*. http://www.dfo-mpo.gc.ca/csas-sccs/

Jung-Schroers, V., Adamek, M., Wohlsein, P., Wolter, J., Wedekind, H., & Steinhagen, D. (2016). First outbreak of an infection with infectious spleen and kidney necrosis virus (ISKNV) in ornamental fish in Germany. *Diseases of Aquatic Organisms*, *119*(3), 239–244. https://doi.org/10.3354/dao02995

Kipp, R. M., Bogdanoff, A. K., Fusaro, A., & Sturtevant, R. (2018). *Piscirickettsia cf. salmonis: U.S. Geological Survey, Nonindigenous Aquatic Species Database, Gainesville, FL, and NOAA Great Lakes Aquatic Nonindigenous Species Information System, Ann Arbor, MI,*. https://nas.er.usgs.gov/queries/GreatLakes/FactSheet.aspx?Species_ID=2658

Lee, D., Yu, Y. bin, Choi, J. H., Jo, A. H., Hong, S. M., Kang, J. C., & Kim, J. H. (2022). Viral Shrimp Diseases Listed by the OIE: A Review. In *Viruses* (Vol. 14, Issue 3). MDPI. https://doi.org/10.3390/v14030585

Leibniz Institut für Gewässerökologie und Binnenfischerei. (2022). *Aquakultur in Zahlen*. https://www.aquakulturinfo.de/aquakultur-zahlen

Leibniz-Institut für Gewässerökologie und Binnenfischerei. (n.d.). *Aquakultur-Info - Arterhaltung*. Retrieved January 29, 2023, from https://www.aquakulturinfo.de/arterhaltung

Lewbart, G. A., & Shivappa., R. (2016). *Spring Viremia of Carp Virus*. https://veteriankey.com/spring-viremia-of-carp-virus/

Lucas, J. (2015). Aquaculture. In *Current Biology* (Vol. 25, Issue 22, pp. R1064–R1065). Cell Press. https://doi.org/10.1016/j.cub.2015.08.013

Molnar, K. (1989). *DISEASES OF AQUATIC ORGANISMS Nodular and epicellular coccidiosis in the intestine of cyprinid fishes* (Vol. 7).

Moore, D. A., Leach, D. A., Bickett-Weddle, D., Andersen, K., Castillo, A. R., Collar, C. A., Higginbotham, G., Peterson, N., Reed, B., & Hartman, M. L. (2010). Evaluation of a biological risk management tool on large western United States dairies. *Journal of Dairy Science*, *93*(9), 4096–4104. https://doi.org/10.3168/jds.2010-3272

Murray, A. G., & Peeler, E. J. (2005). A framework for understanding the potential for emerging diseases in aquaculture. *Preventive Veterinary Medicine*, *67*(2-3 SPEC. ISS.), 223–235. https://doi.org/10.1016/j.prevetmed.2004.10.012

Murray, K. N., Clark, T. S., Kebus, M. J., & Kent, M. L. (2022). Specific Pathogen Free – A review of strategies in agriculture, aquaculture, and laboratory mammals and how they inform new recommendations for laboratory zebrafish. In *Research in Veterinary Science* (Vol. 142, pp. 78–93). Elsevier B.V. https://doi.org/10.1016/j.rvsc.2021.11.005

Murray, K. N., Varga, Z. M., & Kent, M. L. (2016). Biosecurity and Health Monitoring at the Zebrafish International Resource Center. *Zebrafish*, *13*, S30–S38. https://doi.org/10.1089/zeb.2015.1206

Nilsen, F., & Hamre, L. A. (2021, April 2). © *EMBRC. Sea lice: not just any blood and skin-sucking parasite!* https://www.embrc.eu/newsroom/news/sea-lice-not-just-any-blood-and-skin-sucking-parasite

Obosi, K., & Agbeja, Y. E. (2015a). Assessing the Level of Aquaculture Biosecurity Regulations Compliance in Ibadan, Nigeria. *Donnish Journal of Agricultural Research*, *2*(3), 12–019. http://www.donnishjournals.org/djar

Oidtmann, B. C., Crane, C. N., Thrush, M. A., Hill, B. J., & Peeler, E. J. (2011). Ranking freshwater fish farms for the risk of pathogen introduction and spread. *Preventive Veterinary Medicine*, *102*(4), 329–340. https://doi.org/10.1016/j.prevetmed.2011.07.016

Oidtmann, B. C., Thrush, M. A., Denham, K. L., & Peeler, E. J. (2011). International and national biosecurity strategies in aquatic animal health. In *Aquaculture* (Vol. 320, Issues 1–2, pp. 22–33). https://doi.org/10.1016/j.aquaculture.2011.07.032

Oidtmann, B., Peeler, E., Lyngstad, T., Brun, E., Bang Jensen, B., & Stärk, K. D. C. (2013). Risk-based methods for fish and terrestrial animal disease surveillance. In *Preventive Veterinary Medicine* (Vol. 112, Issues 1–2, pp. 13–26). https://doi.org/10.1016/j.prevetmed.2013.07.008

Opiyo, M. A., Marijani, E., Muendo, P., Odede, R., Leschen, W., & Charo-Karisa, H. (2018a. A review of aquaculture production and health management practices of farmed fish in Kenya. In *International Journal of Veterinary Science and Medicine* (Vol. 6, Issue 2, pp. 141–148). Faculty of Veterinary Medicine, Cairo University. https://doi.org/10.1016/j.ijvsm.2018.07.001

Osborn, A., & Henry, J. (2019). The role of aquaculture farm biosecurity in global food security. *Revue Scientifique et Technique (International Office of Epizootics)*, *38*(2), 571–587. https://doi.org/10.20506/rst.38.2.3005

Palić, D., Scarfe, A. D., & Walster, C. I. (2015). A Standardized Approach for Meeting National and International Aquaculture Biosecurity Requirements for Preventing, Controlling, and Eradicating Infectious Diseases. *Journal of Applied Aquaculture*, *27*(3), 185–219. https://doi.org/10.1080/10454438.2015.1084164

Peeler, E. J., & Ernst, I. (2019). Introduction: Improved aquatic animal health management is vital to aquaculture's role in global food security. In *Revue scientifique et technique (International Office of Epizootics)* (Vol. 38, Issue 2, pp. 361–383). NLM (Medline). https://doi.org/10.20506/rst.38.2.2992

Peteri A. (2005). © *FAO 2023. Cyprinus carpio. Cultured Aquatic Species Information Programme*. https://www.fao.org/fishery/en/culturedspecies/cyprinus_carpio/en

Rice, J. C., & Garcia, S. M. (2011a). Fisheries, food security, climate change, and biodiversity: Characteristics of the sector and perspectives on emerging issues. In *ICES Journal of Marine Science* (Vol. 68, Issue 6, pp. 1343–1353). https://doi.org/10.1093/icesjms/fsr041

Rice, J. C., & Garcia, S. M. (2011b). Fisheries, food security, climate change, and biodiversity: Characteristics of the sector and perspectives on emerging issues. In *ICES Journal of Marine Science* (Vol. 68, Issue 6, pp. 1343–1353). https://doi.org/10.1093/icesjms/fsr041

Roberts, H. E., Palmeiro, B., & Weber, E. S. (2009). Bacterial and Parasitic Diseases of Pet Fish. In *Veterinary Clinics of North America - Exotic Animal Practice* (Vol. 12, Issue 3, pp. 609–638). https://doi.org/10.1016/j.cvex.2009.06.010

Seibert, C. H., & Pinto, A. R. (2012). CHALLENGES IN SHRIMP AQUACULTURE DUE TO VIRAL DISEASES: DISTRIBUTION AND BIOLOGY OF THE FIVE MAJOR PENAEID VIRUSES AND INTERVENTIONS TO AVOID VIRAL INCIDENCE AND DISPERSION. *Brazilian Journal of Microbiology*, 857–864.

Soltan, M. (2016). *Aquaculture systems Application of molecular genitics in monitring of plankton resources useful View project daVbdab View project*. https://www.researchgate.net/publication/308928410

Subasinghe, R. P., Delamare-Deboutteville, J., Mohan, C. v., & Phillips, M. J. (2019b). Vulnerabilities in aquatic animal production. *Revue Scientifique et Technique (International Office of Epizootics)*, *38*(2), 423–436. https://doi.org/10.20506/rst.38.2.2996

Tidbury, H. J., Joiner, C. L., Rimmer, G. S. E., Potter, H. v., & Taylor, N. G. H. (2018). The effectiveness of fishery net dips: Advice for the improvement of biosecurity measures. *Journal of Fish Diseases*, *41*(11), 1625–1630. https://doi.org/10.1111/jfd.12868

Viral Haemorrhagic Septicaemia. (n.d.). www.fishpathogens.eu,

Wahli. (2013). Risk assessment for the design of a risk-based surveillance programme for fish farms in Switzerland (in accordance with Council Directive 2006/88/EC of the European Union). In *Rev. sci. tech. Off. int. Epiz* (Vol. 32, Issue 3).

Walker, P. J., & Sittidilokratna N. (2008). Yellow Head Virus. In *Encyclopedia of Virology (Third Edition)* (Vol. 3).

Way, K., Haenen, O., Stone, D., Adamek, M., Bergmann, S. M., Bigarré, L., Diserens, N., El-Matbouli, M., Gjessing, M. C., Jung-Schroers, V., Leguay, E., Matras, M., Olesen, N. J., Panzarin, V., Piačková, V., Toffan, A., Vendramin, N., Veselý, T., & Waltzek, T. (2017). Emergence of carp edema virus (CEV) and its significance to European common carp and koi Cyprinus carpio. In *Diseases of Aquatic Organisms* (Vol. 126, Issue 2, pp. 155–166). Inter-Research. https://doi.org/10.3354/dao03164

Wiencke, Christian. (2011). *Biology of polar benthic algae*. De Gruyter.

Xiang, J. (2015). Recent Major Advances of Biotechnology and Sustainable Aquaculture in China. In *Current Biotechnology* (Vol. 4).