Norwegian School of Economics

Bergen, Spring 2021

The impact of environmental regulations on industry growth

An analysis of the Norwegian salmon farming industry

Karan Sawhney

Supervisor: Linda Nøstbakken

Master Thesis, Economics and Business Administration: Energy Natural Resources and the Environment

NORWEGIAN SCHOOL OF ECONOMICS

"The conservation of natural resources is the fundamental problem. Unless we solve that problem, it will avail us little to solve all others."

Theodore Roosevelt, 1907

Acknowledgements

This thesis is the final step in completing my Master of Science in Economics and Business Administration degree at the Norwegian School of Economics. Exploring the Norwegian salmon farming industry has been a captivating process. The journey allowed me to have numerous interesting conversations with industry professionals. While it was not possible to include all the knowledge gained from these conversations in my thesis, I am grateful for the friendships I built along the way.

First and foremost, I want to thank my supervisor, Linda Nøstbakken, for her extensive guidance and support through this process. I would like to also thank Wenche Grønbrekk from Cermaq, a true advocate for sustainability in aquaculture, for being a great mentor to me. Next, I would like to thank Sindre Grotmol from the University of Bergen and a former member of the Sea Lice Research Center, for his invaluable insights into the sea lice problem in Norway.

Finally, my very profound gratitude to my family in Norway and India. Thank you for your constant support and encouragement and for always believing in me.

This accomplishment would not have been possible without you.

Abstract

Increasing the production of farmed salmon in Norway is an aspiration of the Norwegian government and domestic salmon farming companies. However, given the growing relevance of the environmental movement worldwide, no industry should be operated without considering the correlation between environmental externalities and industry growth. This thesis navigates through the extensive landscape of the salmon farming industry in Norway to understand the dynamic connections between environmental externalities, innovation, and industry growth.

Furthermore, this thesis utilizes a qualitative approach to demonstrate why the industry deems sea lice to be the most significant negative externality and barrier to growth. The importance of ecological innovations in addressing this externality is introduced, and innovations are classified based on the public and private benefits they provide. A detailed overview of the organizations and funding involved in developing these innovations is also presented.

However, the development of innovations is not enough. To achieve environmental goals, companies must adopt them. This thesis aims to understand if widespread adoption of a sustainability enhancing innovations would be possible. A simulation using game theory was conducted to predict companies' strategic behavior in response to environmental regulations.

The analysis revealed that sustainability enhancing innovations that are socially desirable might not achieve widespread adoption. To overcome this, an increase in pre-competitive collaboration amongst salmon farming companies is suggested as a solution.

TABLE OF CONTENTS

Lists

List of Tables

List of Figures

List of Appendices

Abbreviations & Glossary

NINA - Norwegian Institute for nature research

SLRC - Sea Lice Research Center

DWP – Draft white paper

FHF - The Fisheries and Aquaculture Industry's research funding

ASC – Aquaculture Stewardship Council

IMR - Institute of Marine Research

FSA - Norwegian Food Safety Authority

GSI - Global Salmon Initiative

NTNU - Norwegian University of Science and Technology

ONP - Open net pen

MAB - Maximum allowed biomass

COSIA – Canadian Oil Sands Innovation Alliance

1. Introduction

Salmon farming in Norway began in the 1970s. Since then, the industry has mushroomed from small-scale, largely family-owned businesses to an intensive and technology-driven industry (Stien et al., 2020).

The salmon farming industry is of significant national importance to Norway. It has been stated by the Norwegian government, that export revenue from the seafood sector and specifically the aquaculture sector could replace declining petroleum revenues (Ministry of foreign affairs, 2016). Exports have continued to grow over the past two decades, as the production of farmed Atlantic salmon in Norway has risen from 439,874 tons in 2000 to 1,233,200 tons in 2020 (Directorate of Fisheries, 2020). In 2020, the industry exported product worth NOK 70.1 billion (Statistics Norway, 2020).

To farm salmon, specific biological and environmental criteria need to be present. Such conditions include cold water temperatures throughout the year, ranging between 8°C and 14°C, and a sheltered coastline (Global Salmon Initiative, 2015). Due to these specific requirements, salmon is currently farmed in relatively few countries. Four countries are responsible for the majority of global salmon production. Norway has historically been the industry leader and continues to be the largest producer of farmed salmon globally (Stien et al., 2020). Other large producers include Chile (700,600 tons), The United Kingdom (160,500 tons) and Canada (141,800 tons) (Mowi, 2020). Salmon is also produced in the Faroe Islands, Australia, Iceland, and New Zealand. However due to limitations on appropriate farming sites and production capacity, their contribution to global supply is limited (Iversen et al., 2020).

Despite an increase in production output over the years, the number of companies involved in salmon farming has decreased. Prior to 1991, a single company was permitted to own one farm. However, in 1991 the government decided to deregulate ownership requirements. Additionally, companies were granted the right to transfer and mortgage licenses (Ministry of Fisheries and Coastal Affairs, 2005). During the same period, global production costs for salmon farmers declined. This led to an increase in global supply and caused a steep drop in salmon prices. The low prices made it challenging for companies to remain profitable and several salmon farmers in Norway were forced to file for bankruptcy (Marine Fisheries Review, 1991).

The deregulation of ownership requirements, along with a period of low salmon prices, has led to several rounds of consolidation in the industry. In 1999 there were 467 companies farming salmon in Norwegian waters. The ten largest companies during that period contributed 21.6% of total production volume. Today, there are 170 companies holding production licenses and the ten largest companies now account for 66% of total production volume (Appendix 1).

Norwegian salmon farming companies manage their production in two stages. Production begins with the freshwater stage. The freshwater stage is where the hatching of salmon eggs takes place, and juvenile salmon, known as smolts, are raised in freshwater tanks on land. This phase typically lasts for 10 to 16 months. The second stage is known as the 'grow-out phase. This is when the fish are transferred out to seawater sites and grown to full market size. The grow-out phase can last for anywhere between 12 and 24 months (Mowi, 2020).

Salmon farming at sea has traditionally been conducted using an open net pen (ONP). ONPs are still the primary farming method used by salmon farming companies in Norway (PWC, 2021). ONPs are cages made from nets and suspended within a rigid framework. The nets are closed at the bottom and attached to the seafloor using ropes and anchors. The entire system is kept buoyant via buoys and flotation devices used on the surface (Ayer & Tyedmers, 2009). Over time the size and capacity of ONPs have increased, which has allowed companies to increase the number of fish held at a single site (Asche & Bjørndal, 2011).

While the salmon farming industry has consistently been characterized by increasing production. Since 2012, the upward trajectory has stagnated (Figure 1). In recent years new production licenses have been awarded at erratic intervals, making growth uncertain and unpredictable (Bjørndal & Tusvik, 2017).

Uncertainty regarding growth can be attributed to regulations becoming more restrictive and increasing environmental concerns around a parasite known as salmon lice (Bjørndal & Tusvik, 2017). This thesis will discuss the complex challenge environmental regulations have created for the salmon farming industry of Norway. Salmon farming companies are eager to grow; however, they need to do so in a manner that is deemed sustainable by the government and society.

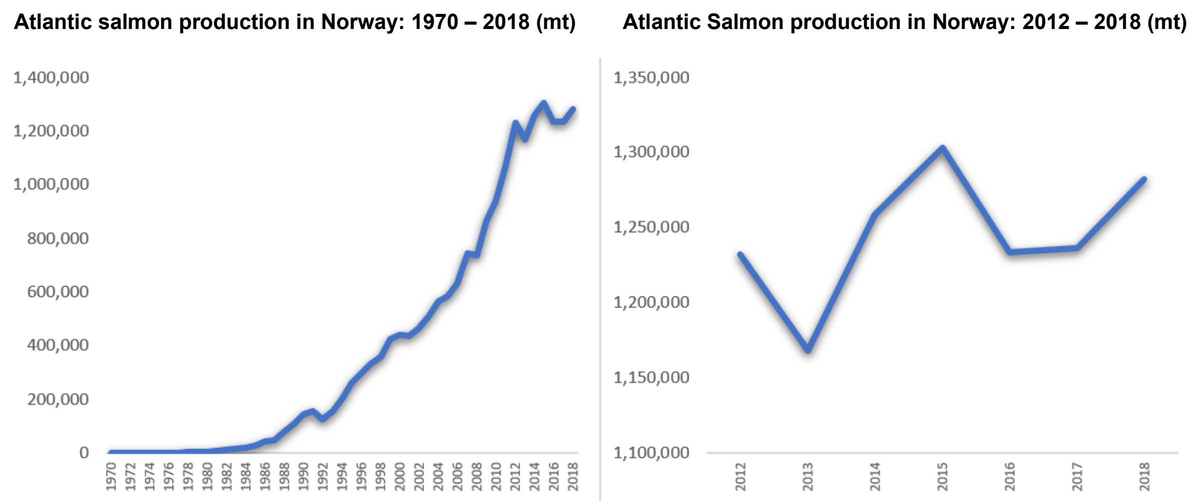


Figure 1. Norwegian Atlantic salmon production in tons between 1970 - 2018, and 2012 - 2018.

Source: Adapted from FishStatJ , FAO, 2020.

1.1 Outline

Norway is currently the largest producer of farmed salmon globally. However, the industry is eager to grow. Section two of this thesis will discuss the rationale of the industry to increase production.

A significant barrier to growth is increased environmental regulations. One of the industry's critical environmental concerns is sea lice that infect wild and farmed salmon. Section three will discuss the need to impose environmental regulations on companies, and section four will introduce the sea lice problem facing the industry.

Section five will present the regulatory framework in Norway and discuss the implications and structure of the new environmental regulations.

Despite imposing new regulations on salmon farming companies, the government has also introduced several unique licenses specifically designed to facilitate growth. These licenses are awarded to companies that can demonstrate a capability to limit the negative externalities of their operations. Section six will elaborate on the various pathways to growth available to companies.

Section seven will introduce the innovation landscape present in Norway to support salmon farming companies. Section eight will then introduce the concept of ecological innovations. Additionally, the various innovations currently being used by the industry will be presented in this section.

Section 9 & 10 will assimilate the information presented to understand how environmental regulations can impact the strategic behavior of salmon farmers in Norway.

1.2 Research Objectives and Question

This paper will work towards to following objectives.

1. To critically review literature into the need to impose environmental regulations on salmon farming companies.

2. To critically review industry literature and establish the role sea lice plays in preventing salmon farming companies from increasing production.

3. To critically review industry literature and present a detailed overview and evaluation of the innovations currently used to address the sea lice problem.

4. To map the innovation landscape in Norway, which allows innovations to be developed and work to understand the level of funding dedicated to addressing sea lice.

Based on the completion of these objectives, this thesis will answer the following research question.

RQ1: If the extensive research and development efforts of industry lead to a radical and sustainability enhancing innovation, would this achieve widespread adoption amongst salmon farming companies and become the industry standard?

2. Rationale for increasing salmon production

Despite recent stagnation in growth, salmon farming companies have enjoyed several years of growing production (Figure 1). It is therefore important to understand why growth is still a key ambition for the industry. This section will explain three reasons why the industry is seeking sustained growth.

2.1 Growing global demand

The growing global demand for salmon represents a significant opportunity for salmon farming companies. Driven by strong demand in almost every region, salmonoids have become the single largest fish commodity by value (FAO, 2020a). Of the various salmonids such as coho salmon, rainbow trout, and wild salmon, Atlantic salmon accounts for the most significant proportion of global export revenue (FAO, 2020a). Additionally, in terms of production quantity, Atlantic salmon has undergone considerable growth. In 2010 global production of farmed Atlantic salmon was 1.4 million tons. By 2018 global production had grown to 2.4 million tons (FAO, 2020a).

Logistics and reputation have helped salmon become a commodity that is consumed in almost 150 countries globally (Asche & Bjørndal, 2017). However developed countries have traditionally driven demand (FAO, 2020a). For example, in the USA, salmon surpassed tuna in 2017 to become the second most consumed seafood in the country, after shrimp (Smejkal & Kakumanu, 2018). Today developed countries continue to dominate salmon imports. In 2019, 82% of salmon exported from Norway was sold to developed nations (Appendix 2).

However, demand in developing countries has now steadily started to increase (FAO, 2020a). The key drivers behind growing demand in developing countries is urbanization, increasing disposable income, and an expansion of the middle class (FAO, 2020a). These changes in wealth distribution can lead to shifts in the eating habits of consumers. Increased disposable income allows consumers to shift from starchy carbohydrates to more protein-rich sources of food, such as fish (Lem et al., 2014; Ray et al., 2013).

The increase in imports of fish in developing countries is currently outpacing developed countries. In 1976, fish imports by developing countries represented 12% of the global total by value, and 19% by weight. In 2018, these figures stood at 31% and 49%, respectively (FAO, 2020a).

As purchasing power increases, consumer preferences also evolve (Akbar, 2011). Countries like Brazil and China, which traditionally did not consume salmon, are now large consumers of high-value species such as salmon and shrimp (FAO, 2020a). In 2000, China imported

10,000 tons of Atlantic salmon; by 2017, this figure had increased to 90,000 tons (Norwegian Seafood Council, 2021).

When predicting global demand, megatrends can be analyzed to understand consumer behavior (Ferreira et al., 2019). A megatrend can be defined as "*a significant movement, pattern, or trend emerging in the macroenvironment likely to have a significant impact on the kinds of products consumers will wish to buy in the foreseeable future*" (Monash Business School, 2018).

One trend that could impact global salmon demand is a larger and older population (Norwegian Seafood Council, 2021). In 2019 there were 703 million people aged 65 or older (United Nations, 2019). Projections estimate that by 2030, the number of individuals aged 65 or older will grow to 1 billion or 12% of the global population (He et al., 2016). This trend will primarily impact European Union countries, North America, and Asia (Lutz & Kc, 2010). This trend is relevant as studies have shown that fish consumption increases a consumer age increases. However, this may vary depending on country and culture (Verbeke & Vackier, 2005).

Another key megatrend is an increasing consumer focus on sustainability. A survey determining the top drives for seafood demand in 2020 found that respondents viewed sustainable production as the most important factor (PWC, 2021). Additionally, a series of studies conducted by the Global Web Index discovered that consumers today express a higher degree of interest in sustainability than ten years ago. In a survey conducted as part of the study, 72% of the respondents stated that sustainability was an essential factor in their decision to purchase a product (Norwegian Seafood Council, 2021).

The increased consumer focus on sustainability has allowed companies to use sustainability as a market driver for growth (Norwegian Seafood Council, 2021). When compared to alternate proteins, farmed salmon represents a highly sustainable source of protein. Table 1 below provides a comparison between the footprint of farmed salmon and alternate protein sources.

Criteria	Salmon	Chicken	Pork	Beef
Carbon Footprint: *Total greenhouse gas emissions (kgCO2e) caused directly and indirectly by the production of 1 (40g) serving.*	**0.6**	0.88	1.3	5.92
Land Use: *The amount of land (m2) needed to produce 100 g of edible protein.*	**3.7**	7.1	11	102
Feed Conversion Ratio: *Quantity of feed (kg) needed to increase the animal's bodyweight by 1kg.*	**1.5**	2	5	10

Table 1. Footprint of protein production (Salmon, Chicken, Pork, Beef)
Source: Global Salmon initiative, 2020.

2.2 Contribution of salmon farming industry to society

In 2012, a study titled "value creation based on productive seas in 2050" was released by the Royal Norwegian Science Society (DKNVS) and the Norwegian Technical Science Academy (Bailey & Eggereide, 2020). This report emphasized the significant value that aquaculture could generate for Norway. The information in the report made a significant impression on the country, and the conservative coalition government in power adopted the report's findings as a national goal (Bailey & Eggereide, 2020).

The industry generates value for society through job creation and local community development. The salmon farming industry is a key source of employment generation in Norway. In 2020 salmon farming companies employed 7,094 individuals (Directorate of Fisheries, 2021). However, due to the extensive supply chain in salmon farming, it is expected that each job in the aquaculture industry creates two or more jobs in related businesses or industries (Sintef, 2009). It is therefore estimated that the salmon farming industry is responsible for 29,000 Norwegian jobs (Seafood Norway, 2018).

Apart from employment, the salmon farming industry contributes to the development of local communities via the aquaculture fund. The aquaculture fund was established in 2016 and is funded by revenue generated from the sale of salmon production licenses. 80% of these funds are distributed to local municipalities. In 2017 the first payment in the amount

NOK 60 million was distributed to local municipalities. In 2018, NOK 2.7 billion was distributed amongst 174 municipalities (Fish Farming Expert, 2019).

Due to benefits provided to society from the aquaculture sector, the government is incentivized to support its growth and development.

2.3 Sustainable Source of Protein

The global population is expected to grow by 15% in 2050 (Fróna et al., 2019). Population growth will require global food systems to produce 50% more food than today. Additionally, due to increased wealth distribution, global demand for animal-based protein is expected to increase by nearly 70% (Fróna et al., 2019).

While agricultural production is critical to meet this growing demand, focusing on this sector alone will not be sufficient. The production of protein is also essential to the global food system. Farming of land-based animals has traditionally been the primary source of protein production (Fróna et al., 2019). However, this industry is now reaching its environmental limits. Suitable land area to raise livestock is limited. Additionally, freshwater resources are scarce, primarily due to competition with cities, factories, and intensive forms of agriculture (Herrero et al., 2018).

Current sources of protein production, while necessary, have proven to be unsustainable and are significant emitters of greenhouse gases. Raising livestock for meat, eggs, and milk alone generates approximately 14.5% of global greenhouse gas emissions. Additionally, global livestock emissions alone are higher than emissions generated from the worldwide transport sector (Herrero et al., 2018).

When compared with livestock, seafood has proved to be a low emission, sustainable source of protein. As farmed salmon has one the lowest footprints of all animal protein (Table 1), it has the ability to contribute towards a sustainable future food system. Therefore, it is essential that as population levels rise, increased demand for food is met by sustainable sources of protein such as farmed salmon.

3. Natural resource governance theory

Salmon farming companies in Norway, benefit from the countries long and sheltered coastline as they use these waters to farm salmon. This section will discuss the need to regulate industries whose activities interact with the natural environment.

Any production process that interacts with the natural environment has the potential to create an externality (Asche & Bjørndal, 2017). An externality refers to the negative impact of a company's activity on society and the environment. It represents an impact that would not occur if the company did not exist (Jørgensen & Pedersen, 2018).

Companies may attempt to correct these externalities by adopting better practices or innovative technology. However, government intervention, in the form of regulation is also required. If unregulated, negative externalities of a business may damage a natural resource or surrounding ecosystems, leading to the resource losing its value (Centemeri, 2009).

Natural resource governance is therefore required to protect natural resources and ecosystems from being damaged. This concept refers to the institutions and processes that determine how power over and responsibility for natural resources are managed (UN Environment Program, 2020).

In this context, the concept of property rights is essential, specifically to whom natural resources belong. Ownership provides the owner with exclusive and guaranteed rights. If an individual owned natural resources, this could lead to the notion of exclusivity. The government, therefore, holds ownership rights for natural resources and provides access to these resources via a *"license to operate"* (The University of Oxford, 2016).

3.1 License to operate

The concept of "license to operate" goes beyond meeting the government's basic legal requirements and regulations. A license to operate is derived from the idea that a company needs implicit or explicit permission from the government before conducting a business that exploits a natural resource (Wilburn & Wilburn, 2014).

Salmon farmers in Norway are granted a license to operate via the issuance of a production license. This license gives them the right to use the countries coastal waters to farm and raise fish (Ministry of Fisheries and Coastal Affairs, 2005).

The term *"social license to operate"* expands on this and includes the acceptance of the local community and society in the region or country where the company conducts business. The term was coined by a former executive of the mining corporation, Placer Dome, in 1997 and has since been used extensively by the business community (Wilburn & Wilburn, 2014). Although applicable to all industries, the term has become synonymous with natural resource and extractive industries (Bice et al., 2017). A company can only obtain a social license to operate through the broad acceptance of its activities by society or the local community (Bice et al., 2017).

When Post, Preston, and Sachs studied the social licenses to operate granted to organizations, they framed the following definition. **"Although the ultimate justification for the existence of the corporation is its ability to create wealth, the legitimacy of the corporation as an institution—its "license to operate" within society, depends not only on its success in wealth creation but also on its ability to meet the expectations of diverse constituents who contribute to its existence and success. These constituencies and interests are the corporation's stakeholders"** (Wilburn & Wilburn, 2014).

In Norway, the social license to operate is essential, as obtaining it is linked to industry growth. To establish new sites or increase production in existing areas, salmon farming companies need the acceptance of local coastal communities that host these sites (Bailey & Eggereide, 2020). While companies are eager to gain this acceptance, the social license to operate has been impacted by concerns about the environmental externalities caused by commercial farming (Wilburn & Wilburn, 2014). Several of these concerns are now being reflected in the governments increased regulation on salmon farming companies (Bailey & Eggereide, 2020).

Strong natural resource governance can incorporate public concerns within political objectives (Bice et al., 2017). However, creating and enforcing regulations that protect the interests of companies and society is a challenge facing the Norwegian government. They are eager to facilitate sustainable growth in the salmon farming industry. However, this must be done in a manner that would be deemed sustainable by society.

3.2 Sea lice as an environmental indicator

Since 2009 there has been a constant debate and increasing pressure from stakeholders to increase regulation on the salmon farming industry (Olsen and Osmundsen, 2017). The focus of the public discussion was primarily on the environmental impacts of salmon farming (Olsen and Osmundsen, 2017). A subsequent assessment conducted in 2011 by the office of the Auditor General of Norway identified several gaps in the industry. The evaluation determined that the government lacked the ability to assess the environmental impact of salmon farming. Therefore, it was concluded that salmon farming activities could not be classified as environmentally sustainable (Bailey & Eggereide, 2020).

In response, the Norwegian government circulated a draft white paper (DWP) to relevant stakeholders for their comments. The focus of the DWP was to address how salmon aquaculture could obtain sustainable growth (Bailey & Eggereide, 2020). The DWP proposed three options to govern the expansion of the industry. The first was to make no changes to current regulation. The second was to set a fixed annual growth rate and the third was to develop a series of environmental indicators that would determine if growth would be permitted (Regjeringen, 2014).

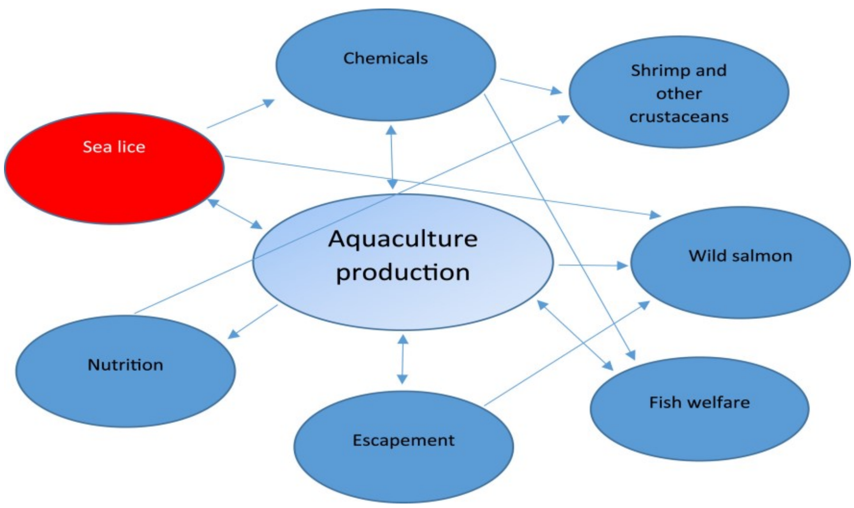


Figure 2: Environmental externalities of commercial salmon farming

Source: Adapted from Olaussen, 2018.

Commercial salmon farming can lead to several environmental externalities (Figure 2). The DWP presented a selection of these as indicators to regulate the industry. The indicators evaluated in the DWP included the number of salmon lice on wild salmon, fish mortality, fish escapes, use of medications, disease, pollution, and emissions (Bailey & Eggereide, 2020). However, eventually, a single indicator was selected, the frequency of sea lice on farmed salmon (Regjeringen, 2014).

4. The Sea Lice Problem

This section will introduce the biology of sea lice and explain why this parasite represents such a significant problem for the industry.

4.1 Biology of sea lice

The Atlantic salmon lice (Lepeophtheirus salmonis salmonis) is a naturally occurring parasite found in marine waters in the northern hemisphere. Atlantic salmon lice (Hencefoth referred to as sea lice) are small crustaceans belonging to a subclass of copepods that feed on the skin, mucus, and blood from fish. These parasites specifically seek out host fishes such as sea trout, rainbow trout and Atlantic salmon (Boxaspen, 2006). Parasitic species can be either generalists or specialists. Generalists can seek out a variety of hosts, whereas specialists infect a single host species (Walker et al., 2017). Sea lice are specialist parasites and specifically seek out trout or Atlantic salmon as hosts and do not infect other species of salmon, such as coho salmon.

Sea lice are entirely dependent on a host to survive and therefore need to maximize their opportunities to locate a host. A single female lice will produce hundreds of egg strings. Producing many offspring allows for a greater chance of survival for the species (Heuch et al., 2000). With this ability, the sea lice create a problem for salmon farming companies, as the high number of offspring can lead to a higher infestation level in ONPs (Revie et al., 2009).

Once the sea lice hatch from the egg, they are in a larvae form and are carried out in the ocean via currents to locate a suitable host. The larvae can survive for up to 12 days in the sea without a host. Sea lice will typically occur in the upper levels of the water column, as this is where salmon tend to swim. The larvae can sense pressure waves generated by swimming fish. The larvae then swim towards the fish, attach themselves using a small pair of hooks and decide if the fish is a suitable host (Sea Lice Research Center, 2019). While extensive research is being undertaken in this field, it is not fully understood how the lice can ascertain whether the fish it has attached to is an Atlantic salmon or another species (FHF, 2020). Once a lice attaches itself to a suitable host, it becomes a parasite and depends entirely on the host for the rest of its life (Sea Lice Research Center, 2019).

4.2 Link between commercial salmon farming and mortality in wild salmon

Sea lice existed in coastal waters long before commercial fish farming began. Historically, lice would infect wild salmon; however, due to a low concentration of wild salmon, the impact of infections was limited (Tingley et al., 1997). When occurring in small numbers, the adverse effects of lice on wild salmon are reduced (Revie et al., 2009). Additionally, wild Atlantic salmon migrate to freshwater rivers to spawn after one or several years (Revie et al., 2009). Sea lice cannot survive in waters with low salt content, such as rivers, and drop off the fish when it returns to freshwater (Sea Lice Research Center, 2021). This periodic change from salt to fresh water is a natural mechanism that prevents sea lice from thriving and protects the well-being of the salmon (Hersoug et al., 2021).

Problems began to arise due to the high density of fish prevalent in commercial farms (Kristoffersen et al., 2014; Torrissen et al., 2013). The high density of fish provided ideal conditions for sea lice to thrive. Due to numerous hosts present in a contained space, the sea lice could quickly locate and attach to a host. Additionally, as farmed Atlantic salmon spend their entire adult lives in seawater, there was no natural mechanism to limit lice levels. Several studies conducted in Norway, Ireland, and Scotland have shown a direct link between commercial salmon farming and increased lice levels in wild Atlantic salmon close to farms (Mills, 2003; Thorstad et al., 2021).

The transmission of lice between farmed and wild salmon occurs as both fish share the same habitat or ecosystem. Therefore, increased sea lice infections amongst farmed salmon can directly lead to higher infection rates in wild salmon (Liu & Bjelland, 2014).

Transmission can also occur when farmed salmon escape from their pens. Escapes can occur during fish handling while removing sea lice, changing nets, or harvesting the fish. Escapes can also occur due to damage or tears in fishing pens, caused by wear and tear, bad weather or collisions with boats (BarentsWatch, 2021). Escaped farmed fish infected by sea lice can then spread these parasites to wild salmon in the surrounding environment. In 2020, there were forty-six reports of escapes, and a total of 57,309 salmon escaped from pens (BarentsWatch, 2021).

The growing number of sea lice is a cause for concern as it impacts the well-being of farmed salmon. However, high levels of sea lice in an area can lead to increased mortality in wild salmon. An extensive study conducted by the Norwegian Institute for Nature Research (NINA) found that eleven attached sea lice can cause the death of an Atlantic salmon. Death occurs because a large number of lice can damage the fins and cause skin lesions in salmon. High lice levels also harm the fish as they lead to increased stress, infections, decreased swimming performance, slower growth, and issues with salt regulation (Revie et al., 2009). National surveys conducted between 2010 and 2014 on rivers in Norway showed an annual mortality of 50,000 adult wild salmon, or an overall loss of 10% of the wild salmon population, due to sea lice (Revie et al., 2009).

5. Regulatory framework

This section will discuss the regulatory framework in Norwegian salmon farming and elaborate on the new environmental regulations introduced by the government.

5.1 Production Licenses

Current regulations require fish farming companies to obtain a valid license to operate before engaging in aquaculture and sea ranching activities (The Aquaculture Act, 2005). Fish farming companies in Norway are subject to several regulations; however, the Aquaculture Act (2005) and the Food Safety Act (2003) are the two most important laws that regulate the industry (Mowi, 2019).

An aquaculture license can be defined as a set of rights and obligations granted to the holder of the license (The Aquaculture Act, 2005). Under this license, the holder is granted the right to produce a specific species, in a specific quantity, at a specific site or location (The Aquaculture Act, 2005).

In Norway, The Ministry of Fisheries and Coastal Affairs (The Ministry) is responsible for administering the Aquaculture Act. However, The Ministry has delegated the power to issue aquaculture licenses to the Directorate of Fisheries (FAO, 2020b). The Directorate of Fisheries is an executive administrative body within The Ministry and is responsible for the coordination, administration, surveillance, and control of the aquaculture sector.

The Aquaculture act also contains a provision that states that the Directorate of Fisheries can limit the number of production licenses issued at a national, regional, or local level (FAO, 2020b).

Salmon farming companies may apply for two types of licenses. The first is a license to farm fish in freshwater (Mowi, 2019). Freshwater farming refers to raising smolts. While permits are required to raise smolts in freshwater, these permits do not limit the quantity of fish per license (BarentsWatch, 2021).

Companies need an alternate license when raising fish in the sea. These are known as grow-out or production licenses (Mowi, 2019). Unlike freshwater licenses, each production license specifies and limits the quantity of fish that may be farmed. This limit is defined by a maximum allowed biomass (MAB) (The Aquaculture Act, 2005). The MAB is the maximum volume of fish a company can hold at sea (Mowi, 2019). One license provides a company with a MAB of 780 tons (FAO, 2020b). In the counties of Troms and Finnmark, the MAB is higher and allows for 945 tons per license (Mowi, 2019).

Additionally, each production area has its own MAB limit. Establishing the production area limit is the responsibility of the Directorate of Fisheries. Generally, sites have a MAB of between 2,340 and 4,680 tons (Mowi, 2019). In addition to limits on volume, in 2013, a new restriction was imposed by the Directorate of Fisheries, limiting the maximum number of individual fish in a single ONP to 200,000 fish (Teknologirådet, 2012).

Companies are unable to farm salmon in the sea without a valid production license. Therefore, to increase production, companies are dependent on the authorities releasing additional production licenses. The decision to release new licenses is made after evaluating a production area's current biomass and assessing the environmental impact of introducing additional fish. If the environmental impact is judged too high, new licenses are not released (Hersoug et al., 2019).

During most of the Norwegian salmon industry's history production licenses were issued to companies for free. However, in 2002, the government introduced a fee of NOK 5 million per license (NOK 4 million for municipalities in North Tromoso and Finnmark). The price was then increased to NOK 8 million in 2009 (NOK 3 million in Finnmark) and subsequently NOK 10 million in 2013 (Hersoug et al., 2019). As demand for production licenses grew but suitable farming sites were limited, the government began to use an auction system as the primary mechanism to sell licenses (Hersoug et al., 2019).

The process to obtain a production license has been illustrated in Appendix 3. The application process is designed to allow an applicant to deal with one public agency, The Directorate of Fisheries. The Directorate of Fisheries then coordinates with the relevant authorities to streamline the application process.

5.2 The Norwegian traffic light system

Sea lice has been a been a problem for the industry since the 1990's and lice levels on farms have been regulated since 1997 (Abolofia et al., 2017). Regulations were initially introduced to limit the maximum number of sea lice per farmed salmon. These regulations were enforced by the Norwegian Food Safety Authority (FSA). Under these regulations the acceptable lice limit was set to 0.5 adult female lice per fish or 3 male adult or pre-adult lice per fish. If this limit was exceeded, companies were required to either administer a medical treatment within two weeks, or slaughter the fish (Abolofia et al., 2017).

The regulation was amended in 2015, when the government released a report titled "Predictable and environmentally sustainable growth in Norwegian salmon – and trout farming." This report first presented the structure of a new traffic light system (Ministry of Trade and Fisheries, 2015). The traffic light system (TLS) came into effect on October 15th 2017, and has since been the primary tool utilized by the government to regulated the growth and environmental impact of salmon farming in Norway (Stien et al., 2020).

Under the TLS, the Norwegian coastline is divided into 13 production zones or production areas (Mowi, 2019). With area 1 located in the south and area 13 in the north. Each zone is classified based on the perceived risk of sea-lice-induced mortality amongst wild salmon (Mowi, 2019). The government quantifies the level of risk by requiring companies to count the number of lice found on their farmed salmon. Each production zone is then assigned a colour to reflect the level of risk. Green indicates low risk; yellow represents a moderate risk, and red represents a high risk (Mowi, 2019).

The TLS rewards production areas that can consistently maintain low lice levels, by offering companies operating within the area an opportunity to increase production capacity. Companies operating in a green area can increase production by up to 6%. However, to be eligible for 6% growth, categorized as "extraordinary growth," a production area is required to meet specific criteria. Sites within the area must achieve an average of less than 0.1 salmon lice per fish during the previous two years (between April 1st and September 30th). Additionally, companies should not administer more than one lice medication treatment during a production cycle (PWC, 2017).

Companies operating in yellow areas are not permitted to increase production capacity until lice levels are reduced. Lastly, the government may penalize companies in red areas by mandating a maximum reduction of 6% in production (Mowi, 2019). Table 2 illustrates the evaluation criteria for each category in the TLS.

	Green Light (Low risk)	**Yellow Light (Moderate Risk)**	**Red Light (High Risk)**
Impact of Wild Salmon	It is probable that < 10 % of the population dies due to lice infection.	It is probable that 10-30% of the population dies due to lice infection.	It is probable that > 30 % of the population dies due to lice infection.
Impact on Production	Up to 2 % growth on existing MAB and up to 4 % growth offered through auction.	No change to MAB.	Up to 6 % decrease in MAB.

Table 2: Traffic light system evaluation criteria
Source: Adapted from PWC, 2017.

While the final determination on a production increase or decrease in a production area is taken by the government, this decision is taken based on the recommendations of a steering committee. The committee members include a representative from the Institute of Marine Research (IMR), NINA, and the Veterinary Institute of Norway. The committee also includes several experts on salmon lice and wild salmon (Stien et al., 2020).

A decision taken by the government can be contradictory to the recommendations made by the steering committee. For example, area 3 (Karmøy to Sotra) did not have to reduce production in 2019, despite the area reporting high mortality levels of wild salmon. The steering committee's recommendation was to classify the area as red. However, the government opted to categorize the zone as yellow and not reduce production (Fish farming expert, 2019). Currently, nine areas have received a green light, two have received a yellow light and two have received red lights (Appendix. 4).

6. Pathways to growth

Figure 3 illustrates the number of production licenses issued between 1999 and 2020. As of 2020, 1,087 production licenses have been issued and total salmon production was 1,364,044 tons. The industry has had an average growth (in terms of production licenses issued) of 1.14% per year between 1999 and 2020.

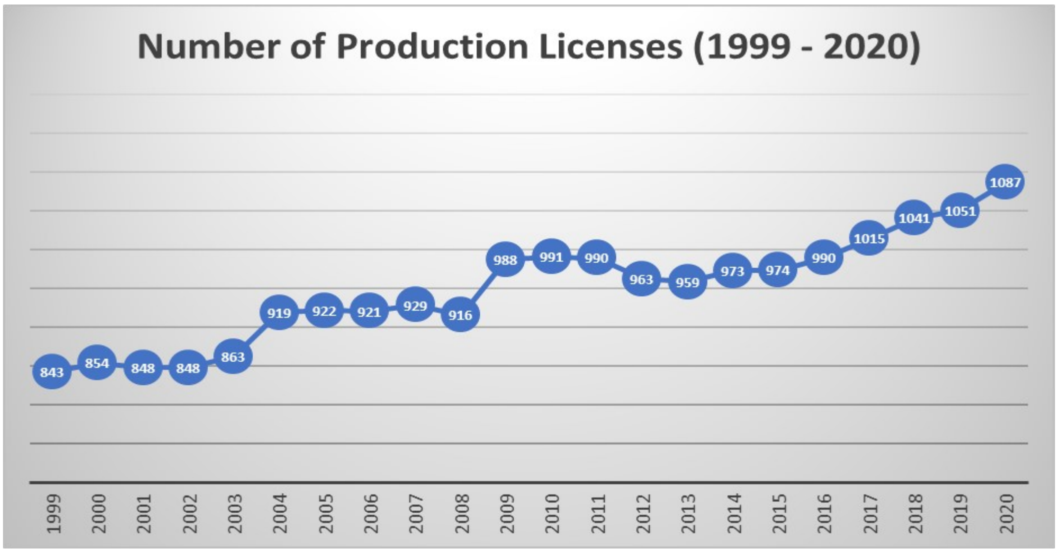


Figure 3: Number of commercial licenses for salmon production

Source: Directorate of Fisheries, 2020

Note: *Excludes licenses for smolts, fingerling, hatcheries.*

The introduction of the TLS meant new production would only be permitted in green areas. However, to facilitate continued growth in the industry, the government introduced several special licenses with unique criteria and requirements. The objective of these licenses is to simultaneously stimulate growth and innovation in the salmon farming industry (Olaussen, 2018).

Additionally, the uncertainty and unpredictability surrounding new licenses for sea farming have led to companies seeking an alternate route to increase production through land-based aquaculture (Bjørndal & Tusvik, 2019). The following subsections will analyze how companies have used the various pathways available to them to increase production.

6.1 Traffic Light System Growth

6.1.1 New production licenses

In 2018 the government decided to allocate new production licenses via an auction. During this round, 15,359 tons of new production capacity were made available to the industry. There was a strong demand for increased production capacity and 14,945 tons, or 97% of the auctioned capacity sold to 14 different companies. In total, this round raised NOK 2,996,728,035 at a price per ton of NOK 195,071 (Directorate of Fisheries, 2018).

Subsequently, the government chose to hold a second auction in 2020. During this round, 27,189 tons of additional capacity were made available to the industry, and the entire quantity was sold. Forty-two companies registered for the auction, of which 30 purchased new licenses. The revenue generated from the auction was NOK 5,975,046,552, which was twice as much as the 2018 auction (Directorate of Fisheries, 2020). The price per ton was higher in 2020 compared to 2018, and each ton was sold for NOK 219,858 (Intrafish, 2019).

New production licenses sold under the TLS have led to industry growth of 42,134 tons.

6.1.2 Increased capacity for existing license holders

Within a few months the TLS being enforcement, the government chose to offer companies holding production licenses in green production areas (1, 7, 8-13) an opportunity to apply for a 2% increase in MAB. The increase in MAB was offered for purchase at a fixed price of NOK 120,000 per ton. In total 47 companies applied, and 441 production licenses were able to increase production by 2%. The increased MAB led to overall production growth of 7,897 tons (Directorate of Fisheries, 2018b). Despite production area 3 and 4 being classified as red in 2018, the government chose not to reduce production capacity (Directorate of Fisheries, 2018b).

In 2020, the government announced a MAB increase of 1% for existing license holders in nine green production zones (Directorate of Fisheries, 2020b). This announcement is estimated to lead to 22,000 to 23,000 tons of increased production capacity (Poulsen, 2020). Eligible companies have been invited to submit applications to the Directorate of Fisheries. However, an official announcement on the number of applications received is yet to be made (Directorate of Fisheries, 2020b).

Increased MAB for existing license holders under the TLS has led to industry growth of 7,897 tons. However, this quantity could increase to 30,897 tons.

6.2 Increased utilization of existing production licenses

A single production license provides a company with a MAB of 780 tons. However, companies are not always able to make full use of this production capacity. The inability to maximize MAB occurs as salmon is a biological product, which requires companies to balance several factors to ensure they never exceed MAB permitted. Companies must consider the growth rate of the fish, the introduction of new smolts, mortalities due to lice or disease, and mortalities from handling (McConnel, 2018). Several of these factors are unpredictable, which makes it challenging to increase MAB utilization.

In 2019, the MAB utilization rate of salmon farmers in Norway was 87% (Mowi, 2019). MAB is closest to full utilization between October and November but never reaches maximum utilization at any point in the year (Mowi, 2019). The current inability to maximize MAB utilization suggests that higher MAB utilization may be a pathway to growth for companies. Additionally, increased MAB utilization would not require companies to purchase new licenses. Companies are currently working towards increasing MAB utilization by introducing larger smolts into pens and increasing the frequency at which fish are introduced into the sea. However, achieving 100% utilization may not be possible (McConnel, 2018).

6.3 Green & Super Green Licenses

In 2012 the Norwegian government trialed a new type of production licenses called "green" and "super-green" licenses (Hersoug et al., 2019). At the time, a 5% expansion of MAB was planned across the country. However, due to strong criticism from the National Audit Office on the inability of the industry to control sea lice, the expansion was canceled (Hersoug et al., 2019). Despite this, companies were still eager to expand production as the market price of salmon was high, and global demand was growing (Hersoug et al., 2019).

In response, the government introduced "green licenses." Green licenses allowed expansion only if companies adopted new production methods to reduce fish escapes and control sea-lice levels (Hersoug et al., 2019). In total 45 licenses were announced and divided into three groups.

Group A provided ten licenses each for the counties of Troms and Finnmark. The cost of each license was NOK 10 million, and to qualify for these licenses, companies needed to achieve an upper limit of 0.25 adult female lice per salmon at sea sites (Hersoug et al., 2019). Group B allocated fifteen licenses, which were available to companies in all counties. These licenses were sold via an auction and required applicants to ensure a lice limit of 0.25 adult female lice per salmon. Additionally, farmers seeking group A or group B licenses also had to commit to operating an existing license with a lice limit of 0.25 adult female lice per salmon (Hersoug et al., 2019).

Lastly, ten group C licenses, or "super green" licenses, were made available to companies across Norway. The criteria for group C licenses were stricter and required an upper lice limit of 0.10 adult female lice per salmon (Hersoug et al., 2019).

The response from the industry was positive, and in total, 255 applications were received. To be eligible for green licenses, companies presented a variety of lice mitigation techniques. These included specialized protective coverings for pens and utilizing lasers to shoot the lice of the fish (Hersoug et al., 2019). In 2015 all 35 licenses from groups A and B were awarded.

Despite leading to an increase in production, green licenses were deemed by many in the industry to be unsuccessful. Firstly, the FSA reported that many farmers were unable to adhere to the lice limits agreed. Secondly, it was unclear what the consequences for non-compliance would be, and if companies would be sanctioned, penalized, or their license revoked if they failed to achieve lice levels. Lastly, the licenses failed to account for fish welfare. Companies had to subject the fish to additional de-licing, such as chemical and mechanical treatments, to meet the stringent lice limits. The increase in the number of treatments led to higher mortality levels of the salmon (Hersoug et al., 2019).

Despite its drawbacks, green licenses led to industry growth of approximately 33,000 tons (Hersoug et al., 2019).

6.4 Developmental Licenses

Developmental licenses were introduced in 2015. Developmental licenses are special production permits awarded to companies that can demonstrate innovations capable of solving environmental or acreage areas impacting the aquaculture sector (Hersoug et al., 2019). In order to be eligible for a developmental license, projects must be based on new technology and involve high investments (Osland, 2019). These licenses were available for a limited time, and companies could only apply between 2015 and 2017 (Hersoug et al., 2019). Due to the high investment costs involved in developing new technology, developmental licenses are granted free to companies for up to 15 years. If the project can meet environmental objectives, companies can covert the developmental license into a commercial license for NOK 10 million.

The Directorate of Fisheries received 104 applications for 898 developmental licenses. Till date 18 applications are accepted, 82 rejected, and four are awaiting a decision (SINTEF, 2021).

The introduction of developmental licenses sparked significant innovation in the industry and led to the advancement of closed containment systems (CCS), semi-closed containment systems (SCCS), and offshore farms. While effective in addressing sea lice, these systems required high capital investments. The cost of installing a 160m closed containment system can range from NOK 40 million to NOK 100 million. Offshore farms could cost up to 1 billion NOK (Greaker et al., 2020) In comparison a similar size ONP costs approximately NOK 2 million (Liu et al., 2016). The high costs associated with these systems suggest that these innovations would not have been possible if the licenses were not issued for free (Greaker et al., 2020).

Despite triggering the development of several innovative technologies, it remains uncertain whether developmental licenses will be a viable route for increased production in the future. The current round saw 90% of all applications rejected (Intrafish, 2020). While the industry expects the government to issue additional developmental licenses, the high criteria needed to qualify may limit growth from such schemes (PWC, 2021).

While several projects are still in the development phase, based on projects currently approved, developmental licenses can lead to 77,000 tons of industry growth (Appendix 5).

6.5 Land-Based Farming

Land-based farming utilizes a large tank or containment system to raise fish on land instead of in the ocean. Currently, companies utilize land-based farms to raise smolts. However, these fish are ultimately transferred to sea sites. Companies are now exploring the possibility of growing the fish from smolt to market size entirely in land-based facilities.

Land-based aquaculture can provide companies with several benefits compared to ocean farming. Land-based systems allow companies to have greater control over the environment of the fish. Companies can determine the ideal water temperature, oxygen content, Ph level, and water quality. This increased control can promote fish health, allowing for superior growth rates, improve feed conversion ratios, and lower disease outbreaks (Bjørndal & Tusvik, 2019). Additionally, as these sites are located on land, companies do not need to be concerned with lice infestation. However, as land-based facilities require construction, equipment, and regular maintenance, the cost of these projects is significantly higher than ONPs. The Norwegian University of Science and Technology (NTNU) estimated the production cost of a land-based grow-out facility to be 42% higher than an ONP (Bjørndal & Tusvik, 2019).

Prior to 2016, land-based farming companies were in direct competition with sea farming companies for a limited number of production licenses. However, the high costs associated with purchasing licensing in addition to the capital required to construct large holding tanks, made land-based projects financially unattractive (Holm et al., 2015).

To allow for a higher number of land-based aquaculture projects, the government decided to segregate licenses for land-based and sea-farming. Land-based farming projects were issued special licenses that had no specific limitation regarding the number of licenses and MAB per license. Additionally, licenses were issued without the need to pay a fee. However, licenses could only be used at a specified site and could not be converted into sea farming licenses (Berge, 2020).

The change in regulation led to a rapid increase in the number of land-based projects in Norway. Currently, 24 projects have been granted land-based farming licenses. However, a majority of these projects are in the planning or construction phase. Currently, only one project from Nordic Aquafarms has harvested market-size fish from a land-based facility (The Fish Site, 2021). Based on the licenses currently issued for land-based projects, this sector could potentially contribute 285,000 tons of industry growth (Appendix 6).

7. Research and development in the salmon farming industry

This section will provide a bird's eye view of the innovation system working to develop solutions to address the sea lice problem. An *innovation system* may be defined as a dynamic network of agents interacting in a specific economic area, under a particular institutional infrastructure and involved in the generation, diffusion, utilization of innovations and technology (Bergesen & Tveterås 2019).

7.1 Public Funding

The Norwegian government plays a vital role in the R&D landscape, specifically in facilitating public funding of research and innovation projects for the industry (Bergesen & Tveterås 2019). The Research Council of Norway (RCN) is the primary channel for public funding in Norway. The RCN is a government-owned organization responsible for setting the national research strategy in Norway (Aslesen, 2019). The organization oversees one-third of all public research funds in the country. Public sector bodies, companies within all industries and research organizations are eligible to apply for funding from the RCN (Research Council of Norway, n.d).

While the RCN funds projects across several industries, it is actively involved in financing projects into sea lice research. Between 2005 and 2021, the RCN has funded 3,567 projects related to sea lice research (Appendix 7). The total amount of funding provided for these projects is NOK 6.03 billion (Research Council of Norway, 2021). These projects cover a wide range of topics, including but not limited to understanding sea lice biology, developing mitigation methods, determining the impact of lice on wild salmon, and supporting various innovations which address the sea lice problem.

7.2 Private Funding

The private sector also plays an important role in funding sea lice research. The Norwegian Seafood Research Fund (FHF) is the primary channel for public funding in Norway.

During the mid-1990s, the seafood industry encouraged the government to strengthen national R&D efforts (FAO, 2013). The companies believed that increased R&D could lead to increased efficiency and boost the competitiveness of the sector. However, there was a lack of consensus on who should fund the increased R&D activity. The industry requested the government to increase grant provisions in the national budget, whereas the government wanted companies to match grants with equity capital and their efforts. However, seafood companies were still relatively small, and employed 50 people or less (FAO, 2013). Due to their small size, it would have been challenging for companies to dedicate financial and human resources towards dedicated R&D activities.

Ultimately, the government decided to impose a levy or tax on seafood exports and use the tax revenue to fund R&D in the seafood industry. The tax amounted to 0.3% of the exported value of seafood (FAO, 2013). The new tax led to the establishment of the FHF.

The FHF is a state-owned limited company owned by the Ministry of Trade, Industry, and Fisheries and entirely financed via the 0.3% levy of exports. The goal of FHF, as stated on their website, is *"to create added value to the seafood industry through industry-based research and development (R&D)"* (FHF, 2009).

The FHF allocates funds for R&D projects in five key areas. These are (i) aquaculture, (ii) fishing, (iii) whitefish (iv) pelagic (v) common focus areas. Despite being a government-owned entity, the FHF possesses a high degree of autonomy. A "professional group" or board appointed by the Norwegian Ministry of Fisheries and Coastal Affairs manages the funds of the FHF. The board is responsible for developing the short and long-term priorities for the fund, based on active and ongoing dialogues with industry players (FAO, 2013). Additionally, researchers, institutions, or individuals can independently submit research proposals to the FHF board for consideration.

Since 2005, the FHF has funded 1,918 projects in the seafood industry. Of which 589 have focused on Aquaculture and 908 on wild fish. A further 420 projects focused on common areas relevant to wild and farmed fish (FHF, 2020). The FHF either partially or entirely funds all projects within this portfolio.

To understand the level of funding contributed to addressing the sea lice problem, an evaluation of all lice-related projects in FHF's portfolio was conducted (Appendix 8). The below table summarizes the total funding provided.

Category	Number of Projects	Total Funding (NOK)
Knowledge of lice.	19	56,705,000
Registration and counting of lice.	8	16,127,000
Breeding, genetics, vaccines, and feed.	16	108,412,000
Dissemination and prevention.	23	113,061,200
Cleaner fish / lice eating fish.	33	199,991,761
Non - drug based de-licing.	21	81,862,792
Drug based de-licing.	9	19,411,000
Total:	**129**	**595,570,753**

Table 3: Overview of FHF funding for salmon lice related projects.

Source: The Fisheries and Aquaculture Industry's research funding, 2020

Note: FHF provided partial or complete funding for all projects listed in table 3. However, projects include funding from private sector companies including the salmon farming companies, pharmaceutical companies, and companies involved in the aquaculture supply chain.

7.3 Organizations conducting R&D

The funding made available by the public and private sector is utilized by universities, research institutions and private companies. There are 20 public, semi-public, and private research institutes in Norway that carry out research related to the salmon aquaculture industry (Aslesen, 2019). Additionally, almost all Norwegian universities undertake aquaculture research and academic teaching (FAO, 2005).

One organization whose research is entirely dedicated to sea lice is the Sea Lice Research Center (SLRC). The SLRC was established by the RCN in 2011 and aims to be the world's leading research center on sea lice. The center works towards understanding sea lice biology and developing new treatments to mitigate lice at farm sites (Sea Lice Research Center, n.d).

The SLRC has received NOK 230 million in funding over eight years and represents a collaborative effort of government, industry, and academia to address the sea lice problem in Norway. The SLRC is supported financially by the RCN, universities (the University of Bergen and Norwegian University of Life Sciences), salmon farming companies (MOWI and Leroy), and private companies (Elanco, Pathogen, and Cargill) (Intrafish, 2018).

Apart from research institutions and universities, companies involved in the aquaculture supply chain also contribute to the R&D landscape. The aquaculture supply chain is made up of feed manufacturers, logistics companies, aquaculture equipment manufacturers, and technology providers (Bergesen & Tveterås, 2019). Several companies in the private sector have internal R&D departments. For example, two of the world's largest aquafeed producers, Biomar and Skretting, have large internal R&D teams researching nutrition and feeding strategies (Bergesen & Tveterås 2019). Both companies are also working to formulate fish feed that contains specific ingredients that can protect salmon from lice. This specially formulated feed would thicken the protective mucus layer on the fish's skin, providing it with increased projection again lice (GSI, 2019b).

Within the salmon farming industry, a market pull creates an incentive for private companies to conduct R&D activities. A market pull occurs when the market demands a product or defines a problem, and innovators responds by producing and delivering a viable solution (Horbach et al., 2012).

Typically, the private sector will invest in R&D activities only if they believe their ideas will achieve success in the market (Greaker et al., 2020). The direct link between sea lice and industry growth has heightened the need to address the sea problem and strengthened the market pull for sea lice related R&D.

The primary benefactors of this innovation system are salmon farming companies. They can access an abundance of knowledge through research reports, published scientific papers, and the several innovations made possible by the extensive R&D landscape. However, the salmon farming companies also contribute to the system by collaborating with private companies, research organizations, and universities (Bergesen & Tveterås, 2019).

Collaboration with salmon farming companies is beneficial for innovators as it provides them with an opportunity to test and evaluate their innovation in actual working environments. A report studying the level of collaboration within the seafood sector of Norway discovered that 20% of aquaculture companies collaborated with universities and research organizations, and 17% collaborated with suppliers to develop innovations for the industry (Bergesen & Tveterås, 2019).

8. Role of innovations in addressing the sea lice problem

8.1 Historical importance of innovation in the salmon farming industry

Research & development in the salmon farming industry and the resulting innovations have historically played a significant role in facilitating industry growth. Most notably, adopting these innovations has allowed farmers to reduce production costs by two-thirds (Asche et al., 2018). Companies were able to pass these gains on to consumers in the form of lower prices, which allowed the industry to increase the competitiveness of its products and obtain a higher market share (Asche, 2008).

One of the first and most crucial R&D projects was established in 1973 by Akvaforsk genetics. The project led to the development of genetically superior salmon, which displayed 77% faster growth rates compared to wild salmon (Gjedrem, 2000). Additionally, in the 1980s, the production time for salmon from hatchling to smolt was typically 2-3 years.

Following extensive R&D efforts, this period was reduced to 6-12 months (Sandvold & Tveteras, 2014).

Another substantial improvement has been the feed conversion ratio for farmed salmon, which has decreased significantly over time (Tveterås, 2002). In the 1980s, three kilograms of feed were required to produce one kilogram of salmon. Today this ratio has reduced to one kilogram of feed to produce one kilogram of salmon (Global Salmon Initiative, 2021). This reduction was possible due to extensive research conducted into understanding the nutritional needs of farmed salmon.

Innovation has also led to improvements in ONP design and size. These innovations have allowed companies to increase production and have much higher stocking densities per site (Asche et al., 2013).

Lastly, innovations in packaging allowed the Norwegian salmon industry to expand its reach and enter foreign markets. The development of leak-proof polystyrene foam packaging allowed companies to ship fresh farmed salmon to the USA and Asia (Asche et al., 2018).

8.2 Ecological innovations

The various innovations listed in the previous section allowed Norwegian salmon farming companies to increase production efficiency and quantity. However, the growing number of fish present in coastal waters magnified the number of hosts for sea lice by a magnitude of 100 (Greaker et al., 2020). While reducing production quantity or stocking density of pens would diminish lice levels, this would be in direct conflict of the industry's objective of seeking growth. Salmon farming companies must therefore once again rely on the development of innovations to assist in industry growth. However, instead of developing innovations to increase productivity, they are seeking innovations that can mitigate the environmental externalities of their operations.

Ecological innovations, also called "eco-innovations," are developed to mitigate the negative environmental externalities of a company (Greaker et al., 2020). Eco-innovations can be defined as *"sustainability-oriented innovations which integrate economic, ecological, and social criteria into new products or processes to benefit companies, the natural environment, and society simultaneously"* (Klewitz & Hansen, 2014).

Apart from reducing negative externalities of business operations, eco-innovations may also be linked to a company's social license to operate. Developing or adopting eco-innovation can allow a company to demonstrate a sense of responsibility for their impact on the natural environment (Horbach et al., 2012).

However, some eco-innovations fail in the marketplace despite their benefits, while others succeed (Greaker et al., 2020). While the primary drivers behind widespread market diffusion is the efficacy and cost of an eco-innovations, the level of acceptance in society must also be considered (Avolio et al., 2014). This is because the level of acceptance can impact the market success of an eco-innovation (Karakaya et al., 2014). Several industries have developed innovations that effectively address environmental externalities. However, a lack of acceptance within society can hinder the widespread diffusion of these solutions (Karakaya et al., 2014).

An example of this is the renewable energy industry. Growing energy demands and increasing awareness of the negative impact of burning fossil fuels led to renewable energy technologies. Despite their ability to eliminate carbon emissions generated by fossil fuels, renewable technologies still require social acceptance (Stigka et al., 2014). Examples of conflicts caused by the development of renewable energy projects can be found in the UK, USA, Mexico, and the Netherlands (Watkin et al., 2012; Van Os et al., 2014; Huesca-Pérez et al., 2016). This suggests that the positive impact of eco-innovations alone may not be sufficient for widespread market diffusion. Companies must work to develop solutions that can also gain acceptance in society.

8.3 Innovations used to address negative externalities

The sea lice problem in Norway and the incentives provided by the various licensing rounds have led to several eco-innovations. The following section will provide a comprehensive overview of the innovations to mitigate sea lice that are currently in use or under development. While many of these innovations have proven highly effective in controlling sea lice levels, none have become the industry standard. This section will also elaborate on how concerns regarding pollution and fish welfare have impeded the social acceptance of specific innovations.

To describe the different approaches taken, the innovations have been classified into six categories (i) chemical and non-chemical, (ii) biological, (iii) mechanical, (iv) alternate production systems, (v) medicinal, and (vi) genetic.

8.3.1 Chemical & non-chemical treatments

One of the first innovations used by salmon farming companies was chemical treatments. Chemical treatments such hydroperoxide and teflubenzuron were administered to the fish to kill sea lice (Greaker et al., 2020). While this initially proved to kill lice effectively, the sea lice proved highly adaptable and became increasingly resistant to the chemicals used (Greaker et al., 2020). Farmers have since attempted to try alternate chemical treatments; however, the problem of resistance has been difficult to overcome (Olaussen, 2018). The use of chemical treatments also raised concerns amongst shrimp and coastal fishermen. They highlighted that the extensive use of chemical treatments was reducing the number of coastal shrimp and other crustaceans (Bailey & Eggereide, 2020). Certain chemicals were also found to be fatal for European lobster larvae present in the marine environment (Parsons et al., 2020). Due to the increasing resistance of lice and the threat of biodiversity loss, chemical treatments have reduced significantly (Olaussen, 2018).

Additionally, several companies now seek to obtain environmental certifications for their sites. Aquaculture Stewardship Council (ASC) is a certification commonly sought by salmon farming companies in Norway. Currently, 325 farm sites in Norway are ASC certified (ASC, 2021). ASC certification requires companies to cease the use of chemical treatments prohibited in any salmon-producing country. Should chemical treatments be required, a veterinarian needs to confirm that the chemicals will not impact fish welfare or affect local biodiversity (ASC, 2020b).

The decline in chemical treatments led to the emergence of non-chemical treatments. An example of this is the “Thermolicer.” The thermometer is a patented method of de-licing fish in a water trap. A thermolicer is placed in a 20-foot container and loaded onto a service vessel, well boat, or barge (Indregard, 2020). Fish are collected and pumped through the thermolicer and bathed in heated saltwater (between 28° and 34° C) for approximately thirty seconds (Indregard, 2020). The high-water temperature causes the lice to release their hold on the fish. This innovation has become the most used non-medicinal treatment for salmon lice in Norway (Stranden, 2020).

While this method has proven effective in ridding the fish of lice, it has raised concerns for the welfare of the fish. In their natural environment, the ideal water temperature for salmon is between 14° and 16° C (NOFIMA, 2019b). Salmon never encounter seawater or fresh water at temperatures created in the thermometer. It was, therefore, initially unclear what impact this treatment was having on the fish. To better understand the effects of thermal de-licing, researchers from the Veterinary Institute of Norway and IMR conducted a study to determine how thermal treatments impacted salmon (Stranden, 2020). The study found that salmon show clear indications of pain when subjected to water temperatures of 28° C or higher. Signs of pain or discomfort included head shaking, faster swimming, arching of the body, and even collisions with the test tank wall (Nilsson et al., 2019).

The findings of the study were published in 2019. In response to the study, the FSA announced that using water temperatures of 28° C or higher would be phased out within two years due to concerns for the welfare of the salmon (Stranden, 2020).

While thermal treatments are still used extensively (Stranden, 2020), freshwater treatments were developed as an alternative (Powell et al., 2015). The use of freshwater to remove lice was based on studies which showed that exposure to water with low salt content could kill sea lice. However, this is dependent on several factors, such as whether the lice are attached to the salmon, the life stage of the lice, the difference in salinity, and how long the exposure lasts (Norwegian Veterinary Institute, 2019). Some researchers initially speculated that lice could develop resistance towards freshwater (Ljungfeldt et al., 2017). However, a report submitted by the Norwegian Veterinary Institute to the FSA debunked this claim. The report stated that while developing resistance was unlikely, lice may develop an increased tolerance to freshwater treatments (Norwegian Veterinary Institute, 2019a).

8.3.2 Biological innovations

Fish farmers have also utilized biological innovations such as cleaner fish to control sea lice levels (Olaussen, 2018). Cleaner fish feed on sea lice and thus can be an effective tool in controlling lice outbreaks in sites. The cleaning fish species commonly used are labrid fish, such as lumpfish and Ballan wrasse (Olaussen, 2018). However, when companies released these cleaner fish into sea sites, their mortality rate was very high. Over six months, the mortality rate for lumpfish and wrasse was 48% and 33%, respectively (Greaker et al., 2020). The high mortality rate raised ethical issues about the over-harvesting and welfare of cleaner fish and raised doubts if cleaner fish could be a viable solution for reducing lice (Greaker et al., 2020).

8.3.3 Mechanical innovations

Companies also make use of mechanical de-licing technologies. Three primary methods of patented mechanical delousing technologies currently exist. These are SkaMik 1.5, the Hydrolicer, and FLS Caligus (Overton et al., 2018). Like thermal treatments, these technologies require the fish to be pumped into a treatment containment system. Once within the system, lice are mechanically removed from the fish using low-pressure nozzles, brushes, or vacuums. However, like thermal treatments, mechanical treatments have also led to concerns about fish welfare. A survey of salmon farming companies found that scale loss, gill bleeding, wounds, and even mortality could occur on fish after mechanical de-licing treatments (Overton et al., 2018).

Treatment category	2012	2013	2014	2015	2016	2017	2018	2019
Thermal	0	0	3	36	685	1,247	1,355	1,461
Mechanical removal	4	2	38	34	331	279	471	738
Fresh water	0	1	1	28	88	96	104	174
Total	**4**	**3**	**42**	**98**	**1104**	**1,622**	**1,930**	**2,373**

Table 4: Number of thermal, fresh water and mechanical treatments administered to farmed salmon.
Source: Norwegian Veterinary Institute, 2019.

8.3.4 *Alternate production systems*

In addition to removing and killing sea lice, companies also use proactive innovations that prevent the fish from being infected by lice. These innovations rely on the use of physical barriers to separate the fish from lice. One such barrier is a "lice skirt." Lice skirts are sheets of material fixed to the top few meters of an ONP, as this is where sea lice commonly occur.

The skirt acts as a shield and prevents the lice from entering the ONP (Stien et al., 2012). While skirts are a cost-effective solution, they can reduce oxygen flow to the fish in pen. The lack of oxygen can severely compromise the fish's respiratory function, which discourages some companies from utilizing lice skirts (Stien et al., 2012).

A new solution was developed to overcome the lack of oxygen, known as the "snorkel". Like skirts, the snorkel creates a physical barrier between the salmon and sea lice. However, the center of the roof is fitted with an enclosed tube or snorkel. The snorkel allows fish to swim to the surface for oxygen within a protected zone away from the sea lice (Oppedal et al., 2017).

Additionally, the snorkel keeps the salmon in deeper water and away from lice that swim close to the surface (GSI, 2019b). Another related innovation is "bubble curtains." Bubble curtains are devices installed around the bottom of a salmon pen and release a line of air bubbles. The air bubbles act as a barrier to prevent lice from entering the pen (GSI, 2019b).

The announcement of developmental and green licenses facilitated the advancement of highly effective solutions such as CCS or S-CCS. These systems are designed to protect farmed salmon from being infected by sea lice while also reducing the possibility of fish escapes (CtrlAqua, 2020). The primary difference between the two enclosures is that CCS are completely enclosed, whereas S-CCS can be un-covered on the surface. However, both systems consist of a physical barrier made from concrete, glass-enforced plastic, or soft polymer fabric, separating the salmon from the external environment (Haaland, 2017). CCS use pumps to draw water from deep sections of the ocean. The water is pumped into the system to facilitate a constant flow of clean oxygenated water. Water pumped into the enclosure may also be treated to adjust water temperature and oxygen level, creating an ideal ecosystem for salmon growth (Haaland, 2017).

8.3.5 *Medicinal innovations*

A challenging yet ambitious goal of the research community has been to develop a vaccine for Atlantic salmon which would protect it from lice infestation. The organizations working on developing a vaccine are the Sea Lice Research Center (SLRC) and the Veterinary Institute of Norway. These organizations actively study sea lice biology and use this information to develop new treatments, such as vaccines, drugs, and dietary supplements.

The SLRC has already worked on several experiments to determine if experimental vaccines can protect salmon from lice, without harming the fish (Sea Lice Research Center, 2019).

An effective sea lice vaccine would be an international breakthrough that will help the global salmon industry eliminate chemical, biological, and mechanical delousing methods. However, developing vaccines against parasites is extremely challenging as it requires a deep understanding of the complex molecular interactions between the host and the parasite. (Kasaija et al., 2020).

8.3.6 *Genetic innovations*

Atlantic salmon are vulnerable to sea lice. However, certain species of Pacific salmon have shown resistance and the ability to defend themselves against lice (FHF, 2020b). Studies have shown that this ability is due to Pacific salmon having a genetically superior immune response compared to Atlantic salmon (Fast, 2014). Researchers believe they may use the genetic traits that allow for salmon lice resistance in Pacific salmon to achieve better lice resistance in Atlantic salmon (FHF, 2020b). Researchers will work to accomplish this using a technology known as CRISPR. CRISPR was developed by scientists Emmanuelle Charpentier and Jenifer Doudna. The scientists won the Nobel prize for chemistry in 2020 for developing this method (Nobel Prize, 2020). CRISPR is a gene-editing method that can be described as sending targeted chemical scissors into cells and making changes by removing or inserting pieces of DNA (Forskningsetikk, 2020).

In 2021, a project consisting of researchers from Norway, Great Britain, the USA, Canada, Sweden, and Australia received funding of NOK 40 million for a project utilizing CRISPR. The study's objective is to determine if genetic editing can lead to high or full salmon lice resistance in Atlantic salmon (FHF, 2020b).

While the idea of lice-resistant Atlantic salmon is extremely promising, researchers and salmon farming companies must consider several risks associated with this project. Currently, in Norway, CRISPR is used on lettuce, strawberries, and garden plants. However, there is a lack of experience with using it on animals. Therefore, it is unclear how altering the genes of salmon will impact the health or behavior of the fish (Science Norway, 2021).

Another consideration to be made is if consumers would be willing to purchase and consume genetically edited fish. In Norway, there is strong opposition against genetically modified organisms (GMO) (Eriksson et al., 2020). While CRISPER is different from GMO, as it does not introduce foreign genetic material from another organism, consumers may not be able to distinguish and opt not to purchase CRISPR-modified salmon (Science Norway, 2021).

Lastly, the industry must also consider political concerns. Currently, the field is regulated by the gene technology act and governed by the FSA. To date, the authorities have rejected genetically modified rapeseed and maize due to the risk that their genes could spread to wild species (Holst-Jensen et al., 2012). It is therefore uncertain if genetically modified salmon would be allowed to enter coastal waters.

8.4 Taxonomy of innovations

The innovations described in the previous section may be classified as radical or incremental (Ettlie et al., 1984). A radical innovation is designed to replace existing technologies and lead to a fundamental shift in how the industry operates (Kemp et al., 1998). Therefore, radical innovations involve the development of an entirely new practice, process, or product (Kemp et al., 1998). Typically, these kinds of innovations result from deliberate R&D activity, require high capital investments, and lead to entirely new industry practices (Kemp et al., 1998). Because these innovations represent a shift from standard business practices, their industry adoption rate may be low, implying a high degree of economic risk for innovators developing them (Greaker et al., 2020). Radical innovations are also called 'discontinuous events' primarily because of the time and investment involved. They are unlikely to occur at frequent intervals (McLoughlin et al., 2000).

Incremental innovations, in comparison, are not as drastic and do not represent a fundamental shift in industry practices (Greaker et al., 2020). These innovations typically involve minor upgrades or improvements to existing techniques, processes, technology, methods, or procedures (Kemp et al., 1998). As these are incremental in nature, they cannot radically transform an industry. These types of innovations occur more frequently compared to radical innovations. However, the rate of occurrence may be different depending on the industry and country (McLoughlin et al., 2000).

Innovations may also be classified as "profit-enhancing" or "sustainability enhancing" (Greaker et al., 2020). Profit enhancing innovations lead to a higher private over public benefit. Adopting these innovations can increase a firm's profitability without addressing the negative externality of the business (Greaker et al., 2020). In the context of salmon farming, an example of a profit-enhancing innovation is offshore salmon farms.

Offshore farms are a radical innovation, as they represent an entirely new farming method and have a significantly higher cost compared to ONPs (El-Thalji, 2019). Despite the higher cost, companies adopting this innovation can produce fish in far larger quantities than using ONPs (El-Thalji, 2019). The increased capacity can lead to higher revenue, which represents a private benefit.

However, the innovation does not contribute to solving the lice problem impacting existing farms in coastal waters. Nor does it reduce infection pressure on wild salmon stocks. Therefore, this innovation fails to provide a public benefit. This innovation can be deemed a profit-enhancing innovation as it primarily benefits the company adopting it.

A sustainability enhancing innovation, in comparison, creates a private and public benefit (Provasnek et al., 2017). An example of such an innovation would be introducing a new species of lice-eating fish. The species would represent an incremental innovation, as lice-eating fish, such as Ballan wrasse, have been used to control lice. However, as discussed, these fish have high mortality rates when introduced into pens. A new species of lice-eating fish would be an improvement that would provide a private benefit. This would occur as the company adopting the innovations will have lower lice levels at their farm. However, lice-eating fish also provides a public benefit, as lower lice levels will benefit neighboring sites and reduce the infection pressure on wild salmon stocks. An additional public benefit would be increased welfare for the lice-eating fish introduced into the pens.

Section 7.3 focused on the effectiveness and shortcomings of various innovations currently being utilized or developed to address the sea lice problem. However, the above taxonomy can be used to classify these innovations based on the benefit they provide.

	Incremental (Minor shift from current methods, lower impact)	**Radical** (Significant shift from current methods, higher impact)
Sustainability Enhancing (Public Benefit)	**(i)** Improved chemicals for de-licing. **(ii)** Use of fresh water for lice treatment. **(iii)**New species of lice eating fish. **(iv)** The snorkel system. **(v)** Mechanical de-licing with higher fish welfare.	**(i)** Closed and semi closed containment systems. **(ii)** Vaccine against sea-lice. **(iii)** Genetically lice-resistant salmon.
Profit Enhancing (Private Benefit)	**(i)** Improved feed formulation.	**(i)** Offshore Salmon Farming. **(ii)** Land Based Salmon Farming.

Table 5 – Taxonomy of ecological innovations.

8.5 Current status of the sea lice problem

Despite various innovations currently available and several others under development, salmon farming companies continue to struggle with sea lice. Sea lice remain a barrier to growth, and in 2020 the government exercised its right to reduce the MAB in production area 4 (Nordhordland to Stadt). Companies operating in the area are now required to reduce production capacity by 6% for two years (Intrafish, 2020). In response to this announcement, 25 salmon farming companies filed a collective lawsuit against the government, suing for lost production volumes and demanding NOK 250 million in compensation. The courts eventually dismissed the case in March 2021, and the companies were required to pay the government's legal costs of NOK 1.8 million (Intrafish, 2020).

Additionally, as companies increase their efforts to reduce sea lice levels, mortality rates of salmon are rising. Therefore, companies are suffering production losses as they attempt to achieve production growth. According to the Norwegian Veterinary Institute's 2019 fish health report, 16% of all farmed salmon died in pens in 2018. The total mortalities amounted to 53 million fish. The report cited injuries after de-licing to be the main reason for mortalities (Veterinary Institute of Norway, 2019).

The sea lice problems also represent a high financial and resource cost to the industry. Apart from the large amounts of public and private funds being allocated to address the problem, NOFIMA estimated that sea lice directly cost salmon farming companies an estimated NOK 4.5 billion per year. This figure includes the cost of de-licing fish and the reduced growth of fish due to de-licing treatments (Iversen et al., 2015).

Therefore, despite the persistent efforts of the researcher community and several pathways to growth provided by the government, the industry is still seeking a solution to the sea lice problem.

The public and private benefits that may arise from environmental regulations are influenced by two actors, the government, and companies (Ramanathan et al., 2016). The objective of the government is to design regulation that allows for both a public and private benefit. However, the level to which regulations can achieve enhanced sustainability depends on an adequate level of involvement and corporation from companies (Ramanathan et al., 2016). While several radical innovations are currently being developed, their effect will be limited if they are not able to achieve widespread diffusion in the industry. The next section will focus on understanding what may prevent companies from adopting an innovation.

8.6 Adoption of innovations

Salmon farming companies can be classified as "large" or "small," depending on their contribution to total salmon production in Norway. Currently, the ten largest companies produce 66% of all salmon in Norway, and the remaining 34% is produced by 80 companies (Mowi, 2019).

Despite variations in company size, production capacity, and resources available, all salmon farming companies are regulated under a common TLS. By classifying the Norwegian coastline into 13 distinct production areas, the TLS has created a degree of interconnectivity between all companies within an area, regardless of company size.

Under previous regulations, companies were independently responsible for maintaining lice levels in their sites, and each company was individually penalized based on the lice levels at their site. However, the TLS has led to an interdependence amongst companies. Under the TLS, lice levels are evaluated across an entire production area. Therefore, if one company adopts strict de-licing measures, but a neighboring company chooses not to, both companies can be penalized.

If all companies within a production area were to corporate and adopt a radical innovation, they would sufficiently reduce lice levels and increase production. Therefore, it would be in the industry's best interest if radical innovations achieved widespread adoption.

However, as discussed, radical innovations are associated with a high cost limiting their ability to achieve widespread adoption. Therefore, the following section will explore if cost is the sole factor inhibiting sustainability, enhancing radical innovations from achieving widespread adoption.

Considering these arguments, the following question is raised: *if the extensive R&D efforts of institutions, private companies, universities, and the salmon industry lead to a truly radical and sustainability enhancing innovation, would this achieve widespread diffusion in the market and become the industry standard?*

9. Methodology

In order to answer the research question posed and understand when companies will take a strategic decision to either adopt or not adopt an innovation, this thesis will make use of game theory. Data collection for this section was based on essays, articles, and research papers on game theory.

Game theory is seen as a powerful tool to model the strategic behavior of companies in situations where interdependence exists (Nikolova & Neycheva, 2014). Interdependence may be defined as a situation where the actions of one "individual" can have a direct impact on one or more other "individuals" (Grønbæk et al., 2020). This interdependence causes each individual to consider the decisions taken by others before formulating their strategy (Davis, 2021).

Game theory was therefore, deemed to be a suitable tool to predict the behavior of salmon farmers, who do not operate in isolation, share the same natural resources with their competitors, and whose actions can directly impact operations in a neighboring farm.

9.1 Introduction to game theory

Game theory is a branch of applied mathematics that provides tools to create a formal representation of a situation where decision-makers interact in a setting of strategic interdependency (Mas-Collel et al., 2012). The theory was first introduced by mathematicians John Von Neumann and Oskar Morgenstern in their book "The Theory of Games and Economic Behavior." Neumann and Morgenstern believed that mathematics developed for physical sciences was not a suitable model for economics. They thought economics was more like a game, where players anticipate each other's moves. To capture this behavior, they proposed a new kind of mathematics called game theory (Davis, 2021).

9.2 Types of games

Game theory models consist of decision-makers, known as "players," who compete with each other and make strategic decisions (Grønbæk et al., 2020). Game theory also has several types of games, each suitable for different situations.

9.3 Strategic behavior

Strategic behavior can be viewed in two ways. The first is the behavior that leads to actions taken by firms intending to influence the market environment in which they compete (Nikolova & Neycheva, 2014). This definition focuses on long-term decisions, such as capital investment, product differentiation, production capacity or R&D. Alternatively, in game theory and economic theory, strategic behavior is an action taken by the company, considering its direct competitors expected actions. This definition views strategic behavior as a short-term decision. However, a common thread between these definitions is that each firm chooses its strategy to maximize profits, given the profit-maximizing decisions of other firms (Nikolova & Neycheva, 2014).

9.4 Free rider problem

The free-rider problem can be viewed as an example of a market failure. It occurs when individuals consume shared resources, but some individuals can consume more than their fair share or pay less than their fair share of the costs. Free riding can lead to an inefficient distribution of goods or services (Hardin & Cullity, 2003).

Free riders can enjoy benefits without contributing to a collective resource. Therefore, there is little or no incentive for them to contribute. This can lead to an inefficiency that prevents the production and consumption of goods and services through conventional free-market methods. A free rider can then broadly be defined as someone who receives a benefit without contributing to the cost (Hardin & Cullity, 2003).

9.5 Collective action problem

A collective action problem occurs where players are presented with two choices. If all players act in their best self-interest or pursue the highest economic benefit, the outcome will be worse for everyone involved. Alternatively, it would be less beneficial for them individually, but benefit the group if they were to choose the other choice. The collective action problem can be viewed as a conflict between self-interest and group interest (Willer, 2009).

9.6 Net pay-off

In game theory, payoffs are representative of the motivations of the players. Payoffs could represent profit, quantity, or other continuous measures. These are known as cardinal payoffs (Shor, 2003).

9.7 Nash equilibrium

The Nash equilibrium is a concept named after Noble Prize-winning economist John Nash. In 1950, John Nash published a one-page article, where he defined an idea of equilibrium for n-player games. This idea has since been widely utilized in economics and other behavioral sciences (Holt, 2004).

The Nash equilibrium is a solution to a game where players cannot improve their payoffs by independently changing their strategy. When Nash equilibrium has been reached, the players have selected an optimal strategy, assuming the other player has selected a strategy and will not change it (Krylovskiy, 2020).

9.8 Formulation of games

The following elements must be considered when setting up a game (Grønbæk et al., 2020).
(i) **The players**: decision makers
(ii) **The rules of the game**: who moves when and what are the moves available to them.

(iii) **The payoffs**: What is the payoff of each player for making a decision, and the payoff in relation to the other player's strategy.
(iv) **The outcomes**: for each set of actions of the players, what is the game's outcome.

9.9 Types of games

For this analysis, this paper will utilize a non-corporative strategic form game. A non-cooperative game was selected as it has the following characteristics. This game form is where commitments (agreements, promises, threats) are not enforceable, and each player acts independently (Maschler et al., 2013). Additionally, each player is free to choose any action from the alternatives available to them (Grønbæk et al., 2020).

The strategic form is a method to represent the game. In this form, the representation of various outcomes is illustrated in the form of a table. In the case of two players, a 2x2 table is used. Each row is labelled with one player's strategy and each column with the strategy of the second player. The cells of the table contain the net payoff for each player (Bonnano, 2008).

10. Analysis

While companies have a variety of technologies and practices that may be adopted to mitigate lice, we assume that there is a single radical innovation available. The innovation selected is a vaccine that prevents farmed salmon from being infected by lice. This innovation was selected as it would be highly effective in preventing sea lice infection and protecting wild salmon stocks. It would also do so without contaminating the surrounding environment. Additionally, it would allow companies to eliminate costs associated with de-licing and prevent a reduction in production capacity. The innovation, therefore, has a clear public benefit and private benefit.

Secondly, extensive funds and resources have been dedicated to developing a vaccine. The SLRC has worked for over eight years to develop a safe and effective vaccine (FSA, 2018). Should the SLRC or any other organization succeed in developing an effective vaccine, it would be valuable for innovators to understand if the industry would adopt it.

Lastly, vaccines have already achieved widespread adoption in the salmon farming industry in Norway. In the late 1980s, a scientist at the Norwegian Veterinary Institute developed a vaccine against a disease infecting salmon called furunculosis. The industry was previously reliant on antibiotics to treat the disease (World Health Organization, 2015). By 1994, companies across Norway had ceased using antibiotics, and vaccination had become the industry standard (World Health Organization, 2015).

Formulation of the Game

To understand the strategic behavior of companies in choosing to either adopt or not adopt the innovation, this analysis will construct a simulation or "game" utilizing game theory. The objective of this game is to understand what conditions need to be present to ensure all "players" adopt the innovation and under what conditions their actions would differ.

(i) The players: Two salmon farming companies operating within the same geographical area in production area 4 (Nordhordaland to Stadt) on the west coast of Norway. The companies are named Company 1 (Hereafter called C1) and Company 2 (Hereafter called C2). C1 is a larger firm and, apart from production area 4, also holds several additional licenses across Norway. C2 is a smaller firm with a limited production capacity and only holds production licenses in production area 4.

(ii) The rules of the game: Figure 4 represents production area 4 and the circles represent production sites located in this area. Within the production area, C1 holds nine production licenses with a total MAB of 7,020 tons. C2 holds two licenses, with a total MAB of 1,560 tones. Production area 4 is currently classified as yellow under the TLS.

Both companies are using traditional ONPs. Additionally, there is limited communication between companies, and each is operating independently of the other. Currently, each company utilizes a combination of de-licing methods. However, a new vaccine has been introduced, which each company may choose to either adopt or not adopt.

Additionally, due to the difference in the quantity of licenses held and related MAB, there is a disparity in the impact on lice levels each company would have, should they choose to adopt. C2 holds two production licenses in the area as opposed to nine held by C1. It is assumed that C2 being the sole adopter would not cause a sufficient drop in lice levels, leading to the production area being classified as red. It is also assumed that C1 being the sole adopter, would lead to a sufficient drop in lice levels, allowing the production area to be upgraded to green. Should neither choose to adopt, the area will be downgraded to red.

Figure 4: Simulation of production area 4 (Nordhordaland to Stadt)

The cost of the innovation assumed in the model refers solely to the cost of purchasing the vaccine. As the R&D to create the vaccine was not conducted by C1 or C2, the cost of developing the innovation is excluded. Additionally, vaccines are currently administrated to most farmed salmon in Norway, and it would be possible to incorporate an additional vaccine into the existing vaccination program. For this reason, the cost of implementing the innovation has also been excluded.

(iii) **The payoffs**:

The optimal scenario for each company, is that which allows it to maximize profits. To define the payoffs in the game, a profit function will be used to evaluate the outcome for each player based on the following variables.

i = Number of permits.

x = Number of fish per permit.

c_0 = Fixed cost per permit.

c_1 = Variable cost per fish.

p = Revenue per permit.

b = Government enforced reduction in number of fish produced.

a = Maximum allowed female lice per fish as per TLS regulation.

v = cost of vaccine per fish.

Based on the defined variables, and the status of the production area as yellow, the profit functions for C1 and C2 can be defined as follows.

$$\textit{Cost per permit} \rightarrow \ (c_i) = \ c_0 + c_1 x$$

$$\textit{Cumulative cost} \rightarrow \ \ C = \ i(c_0 + c_1 x)$$

$$\textit{Revenue per permit} \rightarrow \ P(i) = \ p.x$$

$$\textit{Cumulative revenue} \rightarrow \ \ P = \ i.p.x$$

$$\pi = P - C$$

$$=> \ \pi = i.p.x - i(c_0 + c_1 x)$$

$$=> \ \pi = i(p.x - c_0 - c_1 x)$$

Equation 1

$$=> \ \frac{\pi}{i} = (p - \ c_1)\ x - c_0$$

Should the companies collectively fail to control lice levels, and lice levels > a. The area will be downgraded to red. The profit function is therefore amended to account for reduced production capacity.

$$\textit{Revenue per permit} \rightarrow \ P(i) = \ p.(x - b)$$

$$\textit{Cumulative revenue} \rightarrow \ \ P = i.p.(x - b)$$

$$\pi = P - C$$

$$=> \pi = i.p.(x - b) - i\,(c_0 + c_1 x)$$

$$=> \pi = i\,(p.(x - b) - c_0 - c_1 x)$$

Equation 2

$$=> \frac{\pi}{i} = (p - c_1)\,x - pb - c_0$$

Should the companies adopt the innovation and succeed in achieving lice levels < a. The area will be upgraded to green. The profit function below is amended to account for increased production capacity. However, costs will also increase as the innovation (v) would need to be purchased.

$$\textit{Cost per permit} \rightarrow \ (c_i) = c_0 + c_1 x + v_x$$

$$\textit{Cumulative cost} \rightarrow \ C = i(c_0 + c_1 x + v_x)$$

$$\textit{Revenue per permit} \rightarrow \ P(i) = p.(x + b)$$

$$\textit{Cumulative revenue} \rightarrow \ P = i.p.(x + b)$$

$$\pi = P - C$$

$$=> \pi = i.p\,(x + b) - i(c_0 + c_1 x + v_x)$$

$$=> \pi = i(\,p(x + b) - c_0 - c_1 x - v_x)$$

Equation 3

$$=> \frac{\pi}{i} = (p - c_1 - v)\,x + pb - c_0$$

A condition may also arise, where despite adoption, sea lice levels > a and the production area is downgraded to red. In this scenario a company would be required to pay the cost of the innovation but would also need to reduce production.

$$\boldsymbol{Cost\ per\ permit} \rightarrow\ (\boldsymbol{c_i}) = \boldsymbol{c_0} + \boldsymbol{c_1 x} + \boldsymbol{v_x}$$

$$\boldsymbol{Cumulative\ cost} \rightarrow\ \boldsymbol{C} = \boldsymbol{i(c_0} + \boldsymbol{c_1 x} + \boldsymbol{v_x)}$$

$$\boldsymbol{Revenue\ per\ permit} \rightarrow\ \boldsymbol{P(i)} = \boldsymbol{p.(x - b)}$$

$$\boldsymbol{Cumulative\ revenue} \rightarrow\ \boldsymbol{P} = \boldsymbol{i.p.(x - b)}$$

$$\boldsymbol{\pi = P - C}$$

$$=> \boldsymbol{\pi = i.p\,(x - b) - i(c_0 + c_1 x + v_x)}$$

$$=> \boldsymbol{\pi = i.\,(p(x - b) - c_0 - c_1 x - v_x)}$$

Equation 4

$$=> \boldsymbol{\frac{\pi}{i} = (p - c_1 - v)\,x - pb - c_0}$$

Lastly if the adoption of a single firm is sufficient to allow sea lice levels < a, the production area can be upgraded to green. However, the non-adopting firm will not need to bear the cost of purchasing the innovation. In such a scenario the profit function of the non-adopting firm will be as follows.

$$\boldsymbol{Cost\ per\ permit} \rightarrow\ (\boldsymbol{c_i}) = \boldsymbol{c_0} + \boldsymbol{c_1 x}$$

$$\boldsymbol{Cumulative\ cost} \rightarrow\ \boldsymbol{C} = \boldsymbol{i.(c_0} + \boldsymbol{c_1 x)}$$

$$\boldsymbol{Revenue\ per\ permit} \rightarrow\ \boldsymbol{P(i)} = \boldsymbol{p.(x + b)}$$

$$\boldsymbol{Cumulative\ revenue} \rightarrow\ \boldsymbol{P} = \boldsymbol{i.p.(x + b)}$$

$$\boldsymbol{\pi = P - C}$$

$$=> \boldsymbol{\pi = i.p\,(x + b) - i\,(c_0 + c_1 x)}$$

$$=> \boldsymbol{\pi = i(\,(p - c_1)\,x + pb - c_0)}$$

Equation 5

$$=> \boldsymbol{\frac{\pi}{i} = (p - c_1)\,x + pb - c_0}$$

(iv) **The outcomes**: The following outcomes are possible for this game (1) No adoption: neither player adopts and innovation (2) Complete adoption: both players adopt innovations or (3) Partial Adoption: one player adopts where the second does not.

Game Simulation

The outcomes will be represented in the pay-off matrix below. With the C1 on the left and C2 on the top.

		COMPANY 2	
		Adopt	**Not Adopt**
COMPANY 1	**Adopt**	$\frac{\pi}{i} = (p - c_1 - v)\,x + pb - c_0$ $\frac{\pi}{i} = (p - c_1 - v)\,x + pb - c_0$	$\frac{\pi}{i} = (p - c_1 - v)\,x + pb - c_0$ $\frac{\pi}{i} = (p - c_1)\,x + pb - c_0$
	Not Adopt	$\frac{\pi}{i} = (p - c_1)\,x - pb - c_0$ $\frac{\pi}{i} = (p - c_1 - v)\,x - pb - c_0$	$\frac{\pi}{i} = (p - c_1)\,x - pb - c_0$ $\frac{\pi}{i} = (p - c_1)\,x - pb - c_0$

Figure 5: Adoption of radical innovation.

Complete adoption

Complete adoption represents a scenario where both players invest in purchasing the innovation and choose to adopt. Environmental costs for both players would decrease, as there would no longer be the need to de-lice on site. However, the level of private benefit achieved in this scenario would be dependent on how high the cost associated with v are.

This scenario would create the highest public benefit and lowest lice levels in the production area, and lead to the government allowing production to increase in the area.

Partial adoption

Partial adoption could occur in two ways. The first scenario would be C1 choosing to adopt and C2 not adopting.

This scenario would lead to both a free rider and collective action problem. C1 being the sole adopter would allow the area to be classified as green. However, C2 would not be incentivized to adopt. This would occur as C2 would benefit from increased production capacity without having to bear the cost of the innovation. While it would be beneficial for the collective group if C2 were to adopt, in this scenario C2 is able to achieve a higher pay-off from not adopting.

This scenario would lead to a lower public benefit than complete adoption, as lice would still be present in the area, posing a risk to wild salmon.

Should C1 opt to not adopt, C2 as the sole adopter would lead to the production zone being downgraded to red. In this scenario, C2 would need to bear the cost of the innovation and decrease production. This scenario is unlikely to occur as it would lead to neither public nor private benefit.

No adoption

Neither player adopting would result in both having to decrease production. However, should the cost of the innovation be too high, this scenario could occur as neither company would see the benefit in adopting.

Determining the nash equilibrium

To determine the Nash equilibrium, the dominant strategy of each player will be evaluated. As C1 adopting would have the highest impact on lice levels in the area, it would lead to a higher public benefit if adoption was their dominant strategy. For this to occur, the cost of the innovation (v) is important. For adoption to be the dominant strategy of C1 the following must be true:

$$(p - c_1 - v)x + pb - c_0 \geq (p - c_1)x - c_0$$

$$=> (p - c_1 - v)x + pb \geq (p - c_1)x$$

$$=> (\boldsymbol{p} - \boldsymbol{c_1})\boldsymbol{x} - \boldsymbol{vx} + \boldsymbol{pb} \geq (\boldsymbol{p} - \boldsymbol{c_1})\boldsymbol{x}$$

$$=> \boldsymbol{pb} \geq \boldsymbol{vx}$$

Equation 6

$$=> \frac{\boldsymbol{pb}}{\boldsymbol{x}} \geq \boldsymbol{v}$$

If this condition is satisfied C1, will adopt regardless of what C2 chooses to do and this would form their dominant strategy. If the cost of the innovation is excessively high, and exceeds the benefit from increased production capacity, the dominant strategy of C1 would be to not adopt. Non-adoption would occur if the cost of adopting the innovation would exceed the loss from reducing production. In this scenario, companies achieve a higher net payoff from not adopting.

C2 also holds a dominant strategy in this game. Should C1 adopt, C2 would receive a higher net pay-off by free-riding and not adopting. If C1 were to not adopt, C2 would not adopt as well as doing so would lead to no environmental or financial benefit for them. Therefore, regardless of what C1 chooses to do, C2 will not adopt, and this will be their dominant strategy.

The Nash equilibrium in this game if $\frac{\boldsymbol{pb}}{\boldsymbol{x}} \geq \boldsymbol{v}$ is met is for C1 to adopt and C2 to not adopt.

11. Discussion.

The prime objective of the analysis was to understand if a truly radical eco-innovation would be adopted by all salmon farming companies in a production zone.

The analysis revealed that despite a sustainability enhancing innovation being highly effective and socially desirable, widespread adoption will not occur. Instead, the innovation is likely to achieve partial adoption or not be adopted at all. This behavior can be rationalized by a notion proposed by Ramanathan et al., which suggested that while

companies may view environmental regulations as socially desirable, profit-seeking firms will prioritize private benefits over public benefits.
The three factors which impacted adoption levels were the cost of the innovation, company size (number of licenses held) and the interdependence between companies. The interdependence between companies operating in the same area was a significant factor as it created an incentive for companies to free ride.

The analysis presented in this thesis did have certain limitations as it only demonstrated interactions between two companies operating within a production area. However, in the salmon farming industry in Norway, 20 or more companies can operate within a production area. A high number of companies operating within a production area would lead to greater uncertainly on how much a single company could impact lice levels.

The incentive to free ride under current regulations was corroborated by the research of Greaker et al and Kragesteen et al. Their studies on optimal lice treatments in salmon farm networks found that efficient lice management requires compliance of all companies operating within an area. However, their simulations also suggested that insufficient lice management might lead to a worse economic outcome than no management.

This scenario may be referred to as a tragedy of the commons (Hardin, 1968). This occurs as salmon farms are connected and therefore all companies are collectively responsible negative externalities generated. Fenichel et al, found that the tragedy of commons also occurs in the management of invasive species or insects between land-based farms.

To overcome the free-riding problem Kragesteen et al. suggested the idea of introducing a Pigouvian tax on the industry. A Pigouvian tax is a tax on the business activity that creates the environmental externality. This would suggest directly taxing salmon production. However, such a tax would discourage companies from increasing salmon production. The government is currently seeking to facilitate growth rather than impede it. Therefore, an additional tax may not be a viable solution.

Imposing a Pigouvian tax would be in line with neoclassical economic thinking. This traditional view considers regulations a threat that can negatively impact profitability and competitiveness (Vormedal & Skjærseth, 2019).

However, Ramanathan et al. proposed a more progressive approach and suggested that, for regulation to lead to private and public benefits simultaneously, it must be designed with a degree of flexibility that creates incentives for firms willing to innovate or adopt innovations. In this scenario, companies may view regulations as an opportunity to increase profitability and gain a competitive advantage.

The regulations currently governing the salmon farming industry in Norway are in alignment with Ramanathan's approach. While penalties are involved, the government has also coupled compliance with increased production. Additionally, the introduction of various special licenses has fostered significant innovation in the industry. Therefore, the current regulations do allow salmon farming companies to view environmental regulations as an opportunity to increase market competitiveness (Vormedal & Skjærseth, 2019).

Additionally, if companies can increase revenue while adhering to environmental regulations, this can provide them with a competitive advantage over competitors who cannot do so (Vormedal & Skjærseth, 2019). Lastly, any increase in profits or market share which arises through compliance can compensate for the additional costs required to adhere to stricter regulations (Kennedy, 2019). However, despite the benefits of the current regulations, they have not been sufficient in preventing the free-rider problem (Greaker et al., 2020; Kragstean et al., 2019).

The next concern is the cost of innovations and the role this plays in preventing adoption. This thesis demonstrated that the government currently provides extensive support through the public funding for the development of innovations. Additionally, developmental licenses are issued at no cost as a mean to subsidize and encourage innovation. However, Greaker et al. presented an argument stating that current regulations do not prioritize sustainability enhancing innovations over profit-enhancing innovations. The study suggests that authorities should explore issuing production licenses that include incentives for companies to develop sustainability enhancing innovations such as vaccines or lice-resistant salmon.

To address the free-rider problem and increase environmental compliance, salmon farming companies may seek inspiration from a solution developed by a natural resource-based industry in Canada.

Canada possesses significant amounts of crude oil deposits in the form of oil sands. Oil sands are a mixture of sand, water, clay, and oil (Government of Canada, 2020). To extract the oil, horizontal drilling, and hydraulic fracturing is required (CAPP, 2020). The extraction process generates several externalities such as emission of greenhouse gases, water contamination and biodiversity loss. Due to the externalities of oil sand extraction, the industry receives constant criticism for being one of the largest polluters in Canada (Kelly et al., 2010).

Oil sands extraction companies realized the industry needed to improvement of its overall environmental performance. To address the growing environmental concerns associated with the industry, oil sands extraction companies in Canada established a pre-competitive collaboration-based organization. The organization was named the Canadian Oil Sands Innovation Alliance (COSIA) and was established in 2012. Today COSIA consists of 13 members who represent 90% of the market share in Canada (Silva, 2014). COSIA is built on the belief deep collaboration amongst companies is required to achieve widespread technology development and adoption. The collaboration achieved via the alliance allows for companies to collectively make decisions that benefit the entire industry (COSIA, 2019). A study conducted by Silva, 2014 found that that coordination amongst companies achieved through COSIA was able to mitigate free-riding and improve the industry's environmental performance.

The Norwegian salmon industry could explore adopting the following principles derived from the COSIA charter. Companies operating within an area could enter into a legally binding agreement to collaborate on achieving lice levels that would allow the production area to be classified as green. While it may be challenging to convince all salmon farming companies to corporate. Establishing a production area specific pre-competitive agreement could be a more realistic ambition.

This agreement would also ensure open communication amongst salmon farmers on lice mitigation measures currently being used or being developed. In a highly competitive industry, such as salmon farming, companies may not be willing to share information, as a highly effective innovation can be as a source of competitive advantage. A pre-competitive agreement could therefore be a viable solution to overcome this issue and prevent the free-rider problem discussed.

12. References

Abolofia, J., Asche, F., & Wilen, J. E. (2017). The Cost of Lice: Quantifying the Impacts of Parasitic Sea Lice on Farmed Salmon. *Marine Resource Economics*, *32*(3), 329–349. https://doi.org/10.1086/691981

Akbar, S. (2011). Factors Affecting the Consumers Decision on Purchasing Power. *Journal of Economics and Behavioral Studies*, *2*(3), 108–116. https://doi.org/10.22610/jebs.v2i3.229

Aquaculture Stewardship Council. (2021). *Find a Farm*

Retrieved from: https://www.asc-aqua.org/find-a-farm/

Aquaculture Stewardship Council. (2021). *Sea Lice*

Retrieved from: https://www.asc-aqua.org/aquaculture-explained/why-do-we-need-responsible-aquaculture/salmon-farming/sea-lice/

Asche F. Farming the Sea | Marine Resource Economics: Vol 23, No 4. (2021). Retrieved May 24, 2021, from Marine Resource Economics website: https://www.journals.uchicago.edu/doi/abs/10.1086/mre.23.4.42629678?casa_token

Asche, F. (2008). Farming the sea. *Marine Resource Economics*, *23*(4), 527-547.

Asche, F., & Bjørndal, T. (2011). *The Economics of Salmon Aquaculture*. https://doi.org/10.1002/9781119993384

Asche, F., Cojocaru, A. L., & Roth, B. (2018). The development of large-scale aquaculture production: A comparison of the supply chains for chicken and salmon. *Aquaculture*, *493*, 446–455. https://doi.org/10.1016/j.aquaculture.2016.10.031

Asche, F., Roll, K. H., Sandvold, H. N., Sørvig, A., & Zhang, D. (2013). SALMON AQUACULTURE: LARGER COMPANIES AND INCREASED PRODUCTION. *Aquaculture Economics & Management*, *17*(3), 322–339. https://doi.org/10.1080/13657305.2013.812156

Asche, F., Roll, K. H., Sandvold, H. N., Sørvig, A., & Zhang, D. (2013b). Salmon Aquaculture: Larger Companies and Increased Production. *Aquaculture Economics & Management*, *17*(3), 322–339. https://doi.org/10.1080/13657305.2013.812156

Aslesen, H. W. (2019). Knowledge intensive service activities and innovation in the Norwegian aquaculture industry - Part project report from the OECD KISA study. *Unit.no*. https://doi.org/http://hdl.handle.net/11250/273434

Ayer, N. W., & Tyedmers, P. H. (2009). Assessing alternative aquaculture technologies: life cycle assessment of salmonid culture systems in Canada. *Journal of Cleaner Production*, *17*(3), 362–373. https://doi.org/10.1016/j.jclepro.2008.08.002

Bailey, J. L., & Eggereide, S. S. (2020). Mapping actors and arguments in the Norwegian aquaculture debate. *Marine Policy*, *115*, 103898. https://doi.org/10.1016/j.marpol.2020.103898

BarentsWatch. (2021). *Portal to coastal and sea areas in the north.* Retrieved May 22, 2021, from BarentsWatch website: https://www.barentswatch.no/en/

BarentsWatch. (n.d.). Retrieved April 05, 2021, from https://www.barentswatch.no/en/havbruk/about-norwegian-aquaculture

Berge, A. (2020, August 17). Land-based salmon farming in Norway – laws and regulations. Retrieved from https://salmonbusiness.com/land-based-salmon-farming-in-norway-laws-and-regulations/#_ftn1

Bice, S., Brueckner, M., & Pforr, C. (2017). Putting social license to operate on the map: A social, actuarial and political risk and licensing model (SAP Model). *Resources Policy*, *53*, 46–55. https://doi.org/10.1016/j.resourpol.2017.05.011

Bjørndal, T., & Tusvik, A. (2017). Land based farming of salmon: economic analysis. In *NTNU Working Paper Series* (No. 1). https://doi.org/10.1080/13657305.2019.1654558

Boxaspen, K. (2006). A review of the biology and genetics of sea lice. *ICES Journal of Marine Science*, *63*(7), 1304–1316. https://doi.org/10.1016/j.icesjms.2006.04.017

CAPP. (2020, December 17). Crude Oil Extraction and Drilling Methods. Retrieved May 31, 2021, from https://www.capp.ca/oil/extraction

Canada's Oil Sands Innovation Alliance - COSIA. (2019). Annual Report 2019 | Retrieved May 31, 2021, from Cosia.ca website: https://cosia.ca/annual-report-2019

CtrlAQUA. (2020). *Definitions*. https://ctrlaqua.no/about/definitions/

Davis, M. D. (2021). game theory | Definition, Facts, & Examples. Retrieved May 30, 2021, from https://www.britannica.com/science/game-theory

Dawson, P., McLoughlin, I., Mcloughlin, I., & Preece, D. (2000). *Technology, Organizations and Innovation: Critical Perspectives on Business and Management* (1st ed.).

Diederen, P., Meijl, H., Wolters, A., & Bijak, K. (2015). *Innovation adoption in agriculture innovators, early adopters and laggards*. Retrieved from website: https://hal.archives-ouvertes.fr/hal-01201041/document

Directorate of Fisheries. (2018). Auction of production capacity for aquaculture of food fish in the sea of salmon, trout and rainbow trout in 2018. Available at: https://www.fiskeridir.no/Akvakultur/Tildeling-og-tillatelser/Auksjon-av-produksjonskapasitet/Auksjon-Lukket-budrunde-september-2018

Directorate of Fisheries (2018b). Capacity adjustment / traffic light system 2017-2018. Retrievedfrom:https://www.fiskeridir.no/Akvakultur/Tildeling-og-tillatelser/Kapasitetsjustering-trafikklyssystemet/Kapasitetsjustering-trafikklyssystem-2017-2018

Directorate of Fisheries. (2020). Retrieved May 27, 2021, from English website: https://www.fiskeridir.no/English/Aquaculture/Statistics/Atlantic-salmon-and-rainbow-trout

Directorate of Fisheries (2020a). Auction of production capacity for aquaculture of food fish in the sea of salmon, trout and rainbow trout in 2020. Available at: https://www.fiskeridir.no/Akvakultur/Tildeling-og-tillatelser/Auksjon-av-produksjonskapasitet/Auksjon-august-2020

Directorate of Fisheries (2020b). Capacity adjustment / traffic light system 2020 Available at: https://www.fiskeridir.no/Akvakultur/Tildeling-og-tillatelser/Kapasitetsjustering-trafikklyssystemet/Kapasitetsjustering-trafikklyssystemet-copy

DNV. (2018). *Offshore aquaculture.* Retrieved from: https://www.dnv.com/feature/offshore_aquaculture.html

Drønen, O. A. (2020, August 6). *Mowi among fish farmers suing Norway over production cuts.FishFarmingExpert.com.Retrieved from* https://www.fishfarmingexpert.com/article/norway-fish-farmers-sue-state-over-cuts-to-production-limits/

El-Thalji, I. (2019). Context analysis of Offshore Fish Farming. *IOP Conference Series: Materials Science and Engineering*, *700*, 012065. https://doi.org/10.1088/1757-899x/700/1/012065

El-Thalji, I. (2019). Context analysis of Offshore Fish Farming. *IOP Conference Series: Materials Science and Engineering*, *700*, 012065. https://doi.org/10.1088/1757-899x/700/1/012065

Ettlie, J. E., Bridges, W. P., & O'Keefe, R. D. (1984). Organization Strategy and Structural Differences for Radical Versus Incremental Innovation. *Management Science*, *30*(6), 682–695. https://doi.org/10.1287/mnsc.30.6.682

FAO.(2003). Technology transfer through networks: experiences from the Norwegian seafood industry. Retrieved May 24, 2021, from Fao.org website: http://www.fao.org/3/a0012e/a0012e08.htm#TopOfPage

FAO.(2005). Fisheries & Aquaculture National Aquaculture Sector Overview Retrieved May 24, 2021, from Fao.org website: http://www.fao.org/fishery/countrysector/naso_norway/en

FAO. (2020). *FishStatJ - Software for Fishery and Aquaculture Statistical Time Series* (FAO Global Fishery and Aquaculture Production Statistics Version 2020.1.0).

FAO.(2020a). *The State of World Fisheries and Aquaculture 2020*. https://doi.org/10.4060/ca9229en

FAO.(2020b). *National Aquaculture Legislation Overview - Norway*. http://www.fao.org/fishery/legalframework/nalo_norway/en

Fast, M. D. (2014). Fish immune responses to parasitic copepod (namely sea lice) infection. *Developmental & Comparative Immunology*, *43*(2), 300–312. https://doi.org/10.1016/j.dci.2013.08.019

Fenichel, E. P., & Abbott, J. K. (2014). Natural Capital: From Metaphor to Measurement. *Journal of the Association of Environmental and Resource Economists*, *1*(1/2), 1–27. https://doi.org/10.1086/676034

FHF (2009) Norwegian Seafood Research Fund. Retrieved from https://www.fhf.no/fhf/about-fhf-english/

FHF.(2020).*Prosjektbasen.* Retrieved from https://www.fhf.no/prosjekter/prosjektbasen/

FHF. (2020a). *Host immunity and skin microbiome interplay: Importance for protection against sea lice infestation in Atlantic salmon*.Retrieved May 22, 2021, from Www.fhf.no website: https://www.fhf.no/prosjekter/prosjektbasen/901566/

FHF. (2020b). *Utnytte artsuavhengig variasjon i resistens mot lakselus / Harnessing cross-species variation in sea lice resistance (CrispResist)*. https://www.fhf.no/prosjekter/prosjektbasen/901631/

FHF.(2021).*Project Bank | Salmon Lice* .Retrieved May 22, 2021, from https://www.fhf.no/resultater/utvalgte-tema/lakselus/

Fish Farming Expert. (2019). *Norway councils get £40m from fish farm licence* Retrieved from https://www.fishfarmingexpert.com/article/fish-farming-licence-sales-deliver-40m-for-norway-councils/

Forskingsetikk.(2020). *Omstridt genetisk metode brukes i Norge*. https://www.forskningsetikk.no/ressurser/magasinet/2020-3/omstridt-genetisk-metode-brukes-i-norge/

Fróna, D., Szenderák, J., & Harangi-Rákos, M. (2019). The Challenge of Feeding the World. *Sustainability*, *11*(20), 5816. https://doi.org/10.3390/su11205816

Gjedrem, T. (2000). Genetic improvement of cold-water fish species. *Aquaculture Research*, *31*(1), 25–33. https://doi.org/10.1046/j.1365-2109.2000.00389.x

Gjedrem, T., 2000. Genetic improvement of cold-water fish species. Aquaculture

Gjerde, B., Grisdale-Helland, B., Helland, S.J., Thodesen, J., Korsvoll, S., 1997.

Global Salmon Initiative (2019). *Non-medicinal approaches to sea lice management*. https://globalsalmoninitiative.org/en/our-work/biosecurity/non-medicinal-approaches-to-sea-lice-management/

Global Salmon Initiative. (n.d.). *Protein production facts*, from https://globalsalmoninitiative.org/en/sustainability-report/protein-production-facts/

Global Salmon Inititave. (2015). *About Salmon Farming.* Retrieved from Global Salmon Initiative website: https://globalsalmoninitiative.org/en/about-salmon-farming/

Government of Canada. (2020). What are the oil sands? Retrieved May 31, 2021, from https://www.nrcan.gc.ca/our-natural-resources/energy-sources-distribution/clean-fossil-fuels/what-are-oil-sands/18089

Greaker, M., Vormedal, I., & Rosendal, K. (2020). Environmental policy and innovation in Norwegian fish farming: Resolving the sea lice problem? *Marine Policy*, *117*, 103942. https://doi.org/10.1016/j.marpol.2020.103942

Grønbæk, L., Lindroos, M., Munro, G., & Pintassilgo, P. (2020). *Game Theory and Fisheries Management: Theory and Applications* (1st ed. 2020 ed.). ., .: Springer.

Haaland, S. A. (2017). *Semi-closed containment systems in Atlantic salmon production - Comparative analysis of production strategies* [Norwegian University of Science and Technology]. https://ntnuopen.ntnu.no/ntnu-xmlui/handle/11250/2456881

Hardin, R., & Cullity, G. (2003). The Free Rider Problem (Stanford Encyclopedia of Philosophy). Retrieved May 8, 2021, from Stanford.edu website: https://plato.stanford.edu/entries/free-rider/?source=post_page-----8aca4ca48181

Hersoug, B., Mikkelsen, E., & Karlsen, K. M. (2019). "Great expectations" – Allocating licenses with special requirements in Norwegian salmon farming. *Marine Policy*, *100*, 152–162. https://doi.org/10.1016/j.marpol.2018.11.019

Hersoug, B., Mikkelsen, E., & Osmundsen, T. C. (2021). What's the clue; better planning, new technology or just more money? - The area challenge in Norwegian salmon farming. *Ocean & Coastal Management*, *199*, 105415. https://doi.org/10.1016/j.ocecoaman.2020.105415

Heuch, P. A., Nordhagen, J. R., & Schram, T. A. (2000). Egg production in the salmon louse [Lepeophtheirus salmonis (Krøyer)] in relation to origin and water temperature. *Aquaculture Research*, *31*(11), 805–814. https://doi.org/10.1046/j.1365-2109.2000.00512.x

Hilde Ness Sandvold & Ragnar Tveterås (2014). Innovation and productivity growth in Norwegian production of juvenile salmonids. Aquaculture Economics &Management, 18:2, 149-168, DOI: 10.1080/13657305.2014.903313

Holm, J. C., Vassbotn, K., Hansen, H., Eithun, I., Andreassen, O., Asche, F., and Reppe, F. (2015). Laks på land - en utredning om egne tillatelser til landbasert matfiskoppdrett av laks, ørret og regnbueørret med bruk av sjøvann. Technical report, Oslo

Holst-Jensen, A., Bertheau, Y., de Loose, M., Grohmann, L., Hamels, S., Hougs, L., Morisset, D., Pecoraro, S., Pla, M., den Bulcke, M. V., & Wulff, D. (2012). Detecting un-authorized genetically modified organisms (GMOs) and derived materials. *Biotechnology Advances*, *30*(6), 1318–1335. https://doi.org/10.1016/j.biotechadv.2012.01.024

Horbach, J., Rammer, C., & Rennings, K. (2012). Determinants of eco-innovations by type of environmental impact — The role of regulatory push/pull, technology push and market pull. *Ecological Economics*, *78*, 112–122. https://doi.org/10.1016/j.ecolecon.2012.04.005

Huesca-Pérez, M. E., Sheinbaum-Pardo, C., & Köppel, J. (2016). Social implications of siting wind energy in a disadvantaged region – Mexico. *Renewable and Sustainable Energy Reviews*, *58*, 952–965. https://doi.org/10.1016/j.rser.2015.12.310

Hvas, M., Folkedal, O., & Oppedal, F. (2020). Fish welfare in offshore salmon aquaculture. *Reviews in Aquaculture*, *13*(2), 836–852. https://doi.org/10.1111/raq.12501

Indregard, C. (2020, August 12). *Thermolicer*. ScaleAQ. Retrieved From: https://scaleaq.com/product/thermolicer/?cn-reloaded=1

Intrafish (2018) Norway sea lice center launches effort to secure funding. Retrieved from: https://www.intrafish.com/aquaculture/norway-sea-lice-center-launches-effort-to-secure-funding/2-1-465429

Intrafish. (2019). *Here are the winners in Norway's $670 million salmon farming license* auction. Retrieved from https://www.intrafish.com/salmon/here-are-the-winners-in-norways-670-million-salmon-farming-license-auction/2-1-860253

Intrafish. (2020). *Norwegian salmon farms are becoming less efficient. What's the way forward?* | Retrieved from https://www.intrafish.com/opinion/norwegian-salmon-farms-are-becoming-less-efficient-what-s-the-way-forward-/2-1-934306

Intrafish. (2020a). These futuristic salmon farming concepts could radically reshape the aquaculture sector. Here's where the projects stand | Intrafish. Retrieved from https://www.intrafish.com/technology/these-futuristic-salmon-farming-concepts-could-radically-reshape-the-aquaculture-sector-heres-where-the-projects-stand/2-1-896541

Intrafish. (2021). *Norwegian salmon farmers lose lawsuit against government in "traffic light"* case. Retrieved from https://www.intrafish.com/legal/norwegian-salmon-farmers-lose-lawsuit-against-government-in-traffic-light-case/2-1-982930

Iversen, A., Andreasen, O., Hermansen, Ø., Larsen, T. A., & Terjesen, B. F. (2013). *Oppdrettsteknologi og konkurranseposisjon*. https://www.nofima.no/filearchive/rapport-32-2013-oppdrettsteknologi-og-konkurranseposisjon.pdf

Iversen, A., Asche, F., Hermansen, Ø., & Nystøyl, R. (2020). Production cost and competitiveness in major salmon farming countries 2003–2018. *Aquaculture*, *522*, 735089. https://doi.org/10.1016/j.aquaculture.2020.735089

Iversen, A., Hermansen, Ø., Andreassen, O., Brandvik, R. K., Marthinussen, A., & Nystøyl, R. (2015). Kostnadsdrivere i lakseoppdrett. *Unit.no*. https://doi.org/978-82-8296-336-

Jørgensen S., Pedersen L.J.T. (2018) RESTART: What, Why, How and So What? https://doi.org/10.1007/978-3-319-91971-3_3

Karakaya, E., Hidalgo, A., & Nuur, C. (2014). Diffusion of eco-innovations: A review. *Renewable and Sustainable Energy Reviews*, *33*, 392–399. https://doi.org/10.1016/j.rser.2014.01.083

Kasaija, P. D., Contreras, M., Kabi, F., Mugerwa, S., & de la Fuente, J. de la. (2020). Vaccination with Recombinant Subolesin Antigens Provides Cross-Tick Species Protection in Bos indicus and Crossbred Cattle in Uganda. *Vaccines*, *8*(2), 319. https://doi.org/10.3390/vaccines8020319

Kemp, R., Schot, J., & Hoogma, R. (1998). Regime shifts to sustainability through processes of niche formation: The approach of strategic niche management. *Technology Analysis & Strategic Management*, *10*(2), 175–198. https://doi.org/10.1080/09537329808524310

Klewitz, J., & Hansen, E. G. (2014). Sustainability-oriented innovation of SMEs: a systematic review. *Journal of Cleaner Production*, *65*, 57–75. https://doi.org/10.1016/j.jclepro.2013.07.017

Kragesteen, T. J., Simonsen, K., Visser, A. W., & Andersen, K. H. (2019). Optimal salmon lice treatment threshold and tragedy of the commons in salmon farm networks. *Aquaculture*, *512*, 734329. https://doi.org/10.1016/j.aquaculture.2019.734329

Kristoffersen, A. B., Jimenez, D., Viljugrein, H., Grøntvedt, R., Stien, A., & Jansen, P. A. (2014). Large scale modelling of salmon lice (Lepeophtheirus salmonis) infection pressure based on lice monitoring data from Norwegian salmonid farms. *Epidemics*, *9*, 31–39. https://doi.org/10.1016/j.epidem.2014.09.007

Lekang, O. (2013). *Aquaculture Engineering* (2nd ed.). Wiley-Blackwell.

Lekang, O. I., Salas-Bringas, C., & Bostock, J. C. (2016). Challenges and emerging technical solutions in on-growing salmon farming. *Aquaculture international*, *24*(3), 757-766.

Liu, Y., & Bjelland, H. vanhauwaer. (2014). Estimating costs of sea lice control strategy in Norway. *Preventive Veterinary Medicine*, *117*(3-4), 469–477. https://doi.org/10.1016/j.prevetmed.2014.08.018

Ljungfeldt, L. E. R., Quintela, M., Besnier, F., Nilsen, F., & Glover, K. A. (2017). A pedigree-based experiment reveals variation in salinity and thermal tolerance in the salmon louse,Lepeophtheirus salmonis. *Evolutionary Applications*, *10*(10), 1007–1019. https://doi.org/10.1111/eva.12505

Lutz, W., & KC, S. (2010). Dimensions of global population projections: what do we know about future population trends and structures? *Philosophical Transactions of the*

Royal Society B: Biological Sciences, *365*(1554), 2779–2791. https://doi.org/10.1098/rstb.2010.0133

Marine Fisheries Review. (1991). *A review of world salmon* Retrieved from: https://core.ac.uk/download/pdf/11024439.pdf

Marion Herrero & Margaret Gill. (2018). land and the environmental limits of animal source-food consumption. Retrieved from ResearchGate website: https://www.researchgate.net/publication/328610297_Livestock_land_and_the_environmental_limits_of_animal_source-food_consumption/stats

Mcconnell, E. (2018). *Public Policy Improvements to Norwegian Salmon Aquaculture Operations – A Case Study* [University of Bergen]. http://bora.uib.no/handle/1956/18269

Michaelsen-Svendsen, B. (2019). Implementation of the Traffic Light System in Norwegian salmon aquaculture - success or failure for whom? *Munin.uit.no*. https://doi.org/https://hdl.handle.net/10037/16137

Mills, D. (Ed.). (2003). *Salmon at the Edge*. https://doi.org/10.1002/9780470995495

Ministry of Fisheries and Coastal Affairs. (2005). The Norwegian Aquaculture Act. Retrieved May 26, 2021, from Government.no website: https://www.regjeringen.no/en/dokumenter/the-norwegian-aquaculture-act/id430160/

Ministry of Trade Industry and Fisheries. (2015). *Forutsigbar og miljømessig bærekraftig vekst i norsk lakse- og ørretoppdrett* (Vol. 16).

https://www.regjeringen.no/contentassets/6d27616f18af458aa930f4db9492fbe5/no/pdfs/stm201420150016000dddpdfs.pdf

Monash Business School. (2018). Retrieved from Monash Business School website: https://www.monash.edu/business/marketing/marketing-dictionary/m/megatrend

Mowi. (2020). *Salmon Farming: Industry Handbook 2020*. https://ml.globenewswire.com/Resource/Download/1766f220-c83b-499a-a46e-3941577e038b

Mowi. (2019). *Salmon Farming: Industry Handbook 2019*. https://ml.globenewswire.com/Resource/Download/1766f220-c83b-499a-a46e-3941577e038b

Nilsson, J., Moltumyr, L., Madaro, A., Kristiansen, T. S., Gåsnes, S. K., Mejdell, C. M., … Stien, L. H. (2019). *Veterinary and Animal Science*, *8*, 100076. https://doi.org/10.1016/j.vas.2019.100076

The Nobe Prize. (2020). *Nobel Prizes Retrieved From:* https://www.nobelprize.org/prizes/chemistry/2020/press-release/

Nofima (2019). *Warming seas are bad news for farmed salmon*. https://nofima.no/en/nyhet/2019/11/warming-seas-are-bad-news-for-farmed-salmon/

Norway Exports (2016). *New Development Licenses Spur Ocean Farming* Retrieved from: https://www.norwayexports.no/news/new-development-licenses-spur-ocean-farming/

Norwegian Food Safety Authority. (2018). Vaccination against salmon lice | Mattilsynet. Retrieved from: https://www.mattilsynet.no/dyr_og_dyrehold/dyrevelferd/forsoksdyr/forsoksdyrsoknader/vaccination_against_salmon_lice.32748

Norwegian Seafood Council. (2021). *The recipe for increasing seafood consumption*. Retrieved from: https://en.seafood.no/news-and-media/news-archive/new-report-the-recipe-for-increasing-seafood-consumption/

Norwegian Veterinary Association. (2019). *Preliminary Report* Retrieved from Vetinst.no website: https://www.vetinst.no/rapporter-og-publikasjoner/rapporter/2020/fish-health-report-2019

Norwegian Veterinary Institute (2019a). *The surveillance programme for resistance in salmon lice (Lepeophtheirus salmonis) in Norway 2019* (ISSN 1894–5678). https://www.vetinst.no/en

Olaussen, J. O. (2018). Environmental problems and regulation in the aquaculture industry. Insights from Norway. *Marine Policy*, *98*, 158–163. https://doi.org/10.1016/j.marpol.2018.08.005

Olsen, M. S., & Osmundsen, T. C. (2017). Media framing of aquaculture. *Marine Policy*, *76*, 19–27. https://doi.org/10.1016/j.marpol.2016.11.013

Oppedal, F., Samsing, F., Dempster, T., Wright, D. W., Bui, S., & Stien, L. H. (2017). Sea lice infestation levels decrease with deeper “snorkel” barriers in Atlantic salmon sea-cages. *Pest Management Science*, *73*(9), 1935–1943. https://doi.org/10.1002/ps.4560

Overton, K., Dempster, T., Oppedal, F., Kristiansen, T. S., Gismervik, K., & Stien, L. H. (2018). Salmon lice treatments and salmon mortality in Norwegian aquaculture: a review. *Reviews in Aquaculture*, *11*(4), 1398–1417. https://doi.org/10.1111/raq.12299

Peano, C., Merlino, V. M., Sottile, F., Borra, D., & Massaglia, S. (2019). Sustainability for Food Consumers: Which Perception? *Sustainability*, *11*(21), 5955. https://doi.org/10.3390/su11215955

Poulsen, K. (2020). *Updated traffic light regulation: production of salmon in Norway will increase*. Retrieved from https://salmonbusiness.com/updated-traffic-light-regulation-production-of-salmon-in-norway-will-increase/

Powell, M. D., Reynolds, P., & Kristensen, T. (2015). Freshwater treatment of amoebic gill disease and sea-lice in seawater salmon production. *Aquaculture*, *448*, 18–28. https://doi.org/10.1016/j.aquaculture.2015.05.027

Preece, D.(2000) *Theories, concepts and paradigms* Retrieved from https://abdn.pure.elsevier.com/en/publications/technology-organizations-and-innovation-critical-perspectives-on--4

Provasnek, A. K., Sentic, A., & Schmid, E. (2017). Integrating Eco-Innovations and Stakeholder Engagement for Sustainable Development and a Social License to Operate. *Corporate Social Responsibility and Environmental Management*, *24*(3), 173–185. https://doi.org/10.1002/csr.1406

Provasnek, A. K., Sentic, A., & Schmid, E. (2017). Integrating Eco-Innovations and Stakeholder Engagement for Sustainable Development and a Social License to Operate. *Corporate Social Responsibility and Environmental Management*, *24*(3), 173–185. https://doi.org/10.1002/csr.1406

PWC. (2017). *Seafood Barometer 2017.* Retrieved from PwC website: https://www.pwc.no/no/publikasjoner/pwc-seafood-barometer-2017.pdf

PWC. (2021). *Seafood Barometer 2021.* Retrieved from PwC website: https://www.pwc.no/en/publications/seafood-barometer.html

Ramanathan, R., He, Q., Black, A., Ghobadian, A., & Gallear, D. (2017). Environmental regulations, innovation and firm performance: A revisit of the Porter hypothesis. *Journal of Cleaner Production*, *155*, 79–92. https://doi.org/10.1016/j.jclepro.2016.08.11

Ray, D. K., Mueller, N. D., West, P. C., & Foley, J. A. (2013). Yield Trends Are Insufficient to Double Global Crop Production by 2050. *PLoS ONE*, *8*(6), e66428. https://doi.org/10.1371/journal.pone.0066428

Regjeringen. (2014). *Høring – melding til Stortinget om vekst i norsk lakse- og ørretoppdrett*. Retrieved from https://www.regjeringen.no/no/dokumenter/horing--melding-til-stortinget-om-vekst-i-norsk-lakse--og-orretoppdrett/id2076332/

Research Council of Norway (n.d) Who can apply for funding. Retrieved May 24, 2021, from https://www.forskningsradet.no/en/apply-for-funding/who-can-apply-for-funding/

Research Council of Norway. (2021). *Statistics - Prosjektbanken*. (Retrieved:https://prosjektbanken.forskningsradet.no/en/explore/statistics?Kilde=FORISS&distribution=Ar&chart=bar&calcType=funding&Sprak=no&sortBy=score&sortOrder=desc&resultCount=30&offset=0&Fritekst=Sea%20lice&Ar=2006&Ar=2007&Ar=2008&Ar=2009&Ar=2010&Ar=2011&Ar=2012&Ar=2013&Ar=2014&Ar=2015&Ar=2016&Ar=2017&Ar=2018&Ar=2019&Ar=2020&Ar=2021&Ar=2017

Revie, C., Dill, L., Finstad, B., & Todd, C. (n.d.). *Report from the Technical Working Group on Sea Lice (A sub-group of the Working Group on Salmon Disease) of the Salmon Aquaculture Dialogue*. Retrieved from website: https://www.nina.no/archive/nina/PppbasePdf/temahefte/039.pdf

Sandvold, H.N., Tveteras, R., 2014. Innovation and Productivity Growth in

Salmon Business. (2019). A Particle List of Recent Land Based Salmonid Farms Globally RetrievedFrom: http://nlcar.ca/uploads/1/0/3/2/103263934/global_list_land_based_-_nov_9_2019.pdf

Science Norway. (2021). *Using CRISPR to mass produce sterile farmed salmon and protect wild salmon*. Retrieved From: https://sciencenorway.no/fish-farming-genetics-salmon/controversial-crispr-method-used-to-make-farmed-salmon-sterile/1800908#:%7E:text=The%20Institute%20of%20Marine%20Reseach,and%20we%20ended%20up%20switching.

Sea Lice Research Center (n.d) Home Page.

Retrieved May 24, 2021, from

https://slrc.w.uib.no/

Sea Lice Research Center. (2021). What is a sea louse? Retrieved May 11, 2021, from W.uib.no website: https://slrc.w.uib.no/about-sea-lice/what-is-a-sea-louse/

Sea Lice Research Center. (2021a) The Atlantic Salmon Louse. Retrieved May 11, 2021, from W.uib.no website: https://slrc.w.uib.no/about-sea-lice/the-atlantic-salmon-louse/

Seafood Norway. (2018). *Sustaining communities and feeding the world.* Selection Criteria for Growth and Feed Utilisation). Rep. No. 39/97 AKVAVORSK.

Shephard, S., & Gargan, P. (2017). Quantifying the contribution of sea lice from aquaculture to declining annual returns in a wild Atlantic salmon population. *Aquaculture Environment Interactions*, *9*, 181–192. https://doi.org/10.3354/aei00223

Shor, M. (2003). Citation information for dictionary entries at Game Theory .net. Retrieved May 8, 2021, from Gametheory.net website: https://www.gametheory.net/dictionary/CitationInformation.html

Silva, E. (2014). Canada's Oil Sands Innovation Alliance: Strategic Rationale and Effects. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.2431306

SINTEF (2009). *Value Created from Productive Oceans* Retrievedfrom:https://www.sintef.no/contentassets/f025260af6b8435394eced5e03939e11/value-created-from-productive-oceans-in-2050.pdf/

SINTEF. (2020). *Develop* Retrieved from: https://www.sintef.no/en/projects/2020/develop/

Smejkal, G. B., & Kakumanu, S. (2018). Safely meeting global salmon demand. *Npj Science of Food*, *2*(1). https://doi.org/10.1038/s41538-018-0025-5

Statistics Norway. (2020). *Aquaculture (terminated in Statistics Norway)* Retrieved from: https://www.ssb.no/en/fiskeoppdrett/

Statistics Norway (2020a) Aquaculture. Number of licences running (C) (closed series) 1994 - 2019. (2020). Retrieved May 24, 2021, from https://www.ssb.no/en/statbank/table/08967/

Stien, L. H., Nilsson, J., Hevrøy, E. M., Oppedal, F., Kristiansen, T. S., Lien, A. M., & Folkedal, O. (2012). Skirt around a salmon sea cage to reduce infestation of salmon lice resulted in low oxygen levels. *Aquacultural Engineering*, *51*, 21–25. https://doi.org/10.1016/j.aquaeng.2012.06.002

Stien, L. H., Tørud, B., Gismervik, K., Lien, M. E., Medaas, C., Osmundsen, T., . . . Størkersen, K. V. (2020). Governing the welfare of Norwegian farmed salmon. https://doi.org/10.1016/j.marpol.2020.103969

Stigka, E. K., Paravantis, J. A., & Mihalakakou, G. K. (2014). Social acceptance of renewable energy sources: A review of contingent valuation applications. *Renewable and Sustainable Energy Reviews*, *32*, 100–106. https://doi.org/10.1016/j.rser.2013.12.026

Stranden, A. L. (2020, February 5). *Every year, 50 million cleaner fish die in Norwegian fish farms*. Science Norway. https://sciencenorway.no/animal-welfare-fish-farming-salmon-industry/salmon-in-pain-when-warm-water-is-used-as-delousing-treatment/1632078

Teknologirådet. (2012). *Fremtidens lakseoppdrett*. https://teknologiradet.no/wp-content/uploads/sites/105/2018/04/Rapport-Fremtidens-lakseoppdrett.pdf

The Fish Site. (2021). *Results from Norway's first land-based salmon farm*. Retrieved from: Thefishsite.com website: https://thefishsite.com/articles/results-from-norways-first-land-based-salmon-farm

Thorstad, E. B., Økland, F., Finstad, B., Sivertsgård, R., Plantalech, N., Bjørn, P. A., & McKinley, R. S. (2021). Fjord migration and survival of wild and hatchery-reared Atlantic salmon and wild brown trout post-smolts. *Developments in Fish Telemetry*, 99–107. https://doi.org/10.1007/978-1-4020-6237-7_11

Tingley, G. (1997). The occurrence of lice on sea trout (Salmo trutta L.) captured in the sea off the East Anglian coast of England. *ICES Journal of Marine Science*, *54*(6), 1120–1128. https://doi.org/10.1016/s1054-3139(97)80017-3

Torrissen, O., Jones, S., Asche, F., Guttormsen, A., Skilbrei, O. T., Nilsen, F., … Jackson, D. (2013). Salmon lice - impact on wild salmonids and salmon aquaculture. *Journal of Fish Diseases*, *36*(3), 171–194. https://doi.org/10.1111/jfd.12061

TVETERÅS, S. (2002). Norwegian Salmon Aquaculture and Sustainability: The Relationship Between Environmental Quality and Industry Growth. *Marine Resource Economics*, *17*(2), 121–132. https://doi.org/10.1086/mre.17.2.42629356

Tveterås, S., 2002. Norwegian Salmon Aquaculture and Sustainability: The

United Nations Environmental Program. (2020). Natural Resource Management. Retrieved May 26, 2021, from UNEP - UN Environment Programme website: https://www.unep.org/explore-topics/disasters-conflicts/where-we-work/sudan/natural-resource-management

United Nations. (2019). *World Ageing population.* Retrieved from: https://www.un.org/en/development/desa/population/publications/pdf/ageing/WorldPopulationAgeing2019-Highlights.pdf

University of Oxford. (2016). *Who owns our natural resources?* Retrieved May 26, 2021, from https://www.ox.ac.uk/news/science-blog/who-owns-our-natural-resources

Van Os, H. W., Herber, R., & Scholtens, B. (2014). Not Under Our Back Yards? A case study of social acceptance of the Northern Netherlands CCS initiative. *Renewable and Sustainable Energy Reviews*, *30*, 923–942. https://doi.org/10.1016/j.rser.2013.11.037

Verbeke, W., & Vackier, I. (2005). Individual determinants of fish consumption: application of the theory of planned behaviour. *Appetite*, *44*(1), 67–82. https://doi.org/10.1016/j.appet.2004.08.006

Vormedal, I., & Skjærseth, J. B. (2019). The good, the bad, or the ugly? Corporate strategies, size, and environmental regulation in the fish-farming industry. *Business and Politics*, *22*(3), 510–538. https://doi.org/10.1017/bap.2019.30

Walker, J. G., Hurford, A., Cable, J., Ellison, A. R., Price, S. J., & Cressler, C. E. (2017). Host allometry influences the evolution of parasite host-generalism: theory and meta-analysis. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *372*(1719), 20160089. https://doi.org/10.1098/rstb.2016.0089

Watkin, L. J., Kemp, P. S., Williams, I. D., & Harwood, I. A. (2012). Managing Sustainable Development Conflicts: The Impact of Stakeholders in Small-Scale Hydropower Schemes. *Environmental Management*, *49*(6), 1208–1223. https://doi.org/10.1007/s00267-012-9857-y

Wilburn, K. M., & Wilburn, R. (2014). Social License to Operate as a Business Strategy. Retrieved May 26, 2021, from undefined website: https://www.semanticscholar.org/paper/Social-License-to-Operate-as-a-Business-Strategy-Wilburn-Wilburn/2dc7f44b9648e7e975706754c44bc3a127661916

Willer, R. (2009). Groups Reward Individual Sacrifice: The Status Solution to the Collective Action Problem. *American Sociological Review*, *74*(1), 23–43. https://doi.org/10.1177/000312240907400102

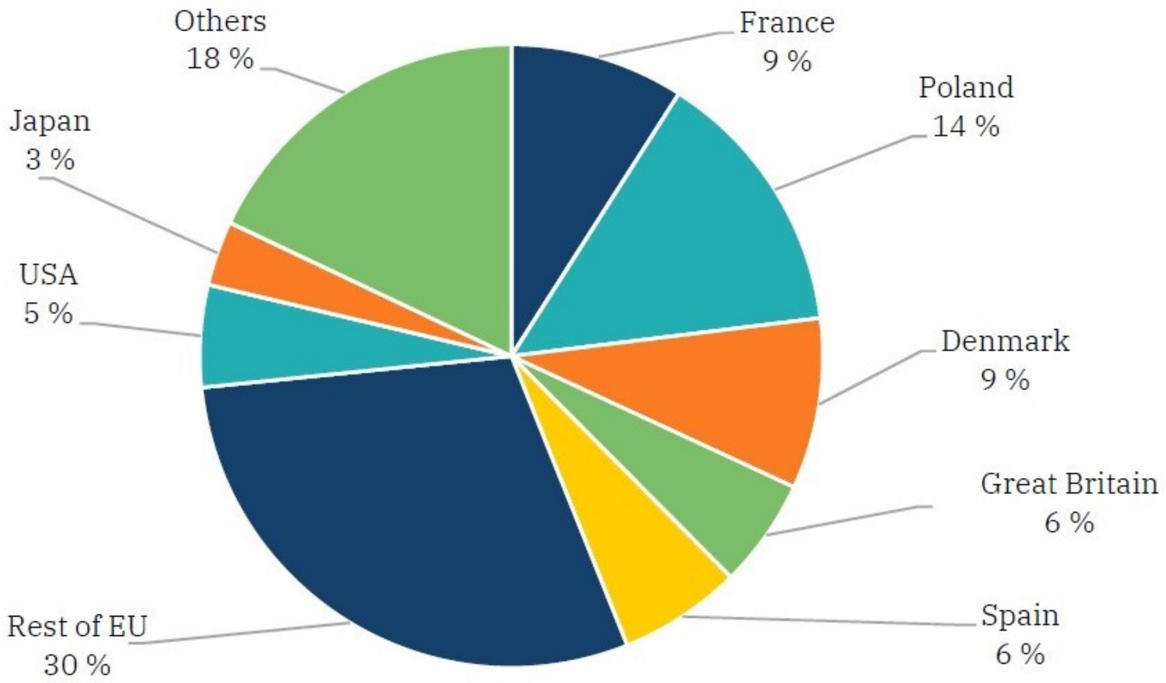
13. APPENDIX

APPENDIX 1 - Number of Companies farming Salmon in Norway and Percentage of sale for the 10 largest companies by year.

Year	Number of Companies	Sales of 10 largest companies (%)
1999	467	21.6
2000	296	32.8
2001	273	32.6
2002	288	33.4
2003	278	41.3
2004	262	41.2
2005	248	47.6
2006	226	48.4
2007	201	58.4
2008	186	63.9
2009	182	65.7
2010	171	64.5
2011	176	65.8
2012	164	69.1
2013	158	68.0
2014	147	69.9
2015	162	68.9
2016	165	67.9
2017	175	67.1
2018	174	67.3
2019	170	66.0

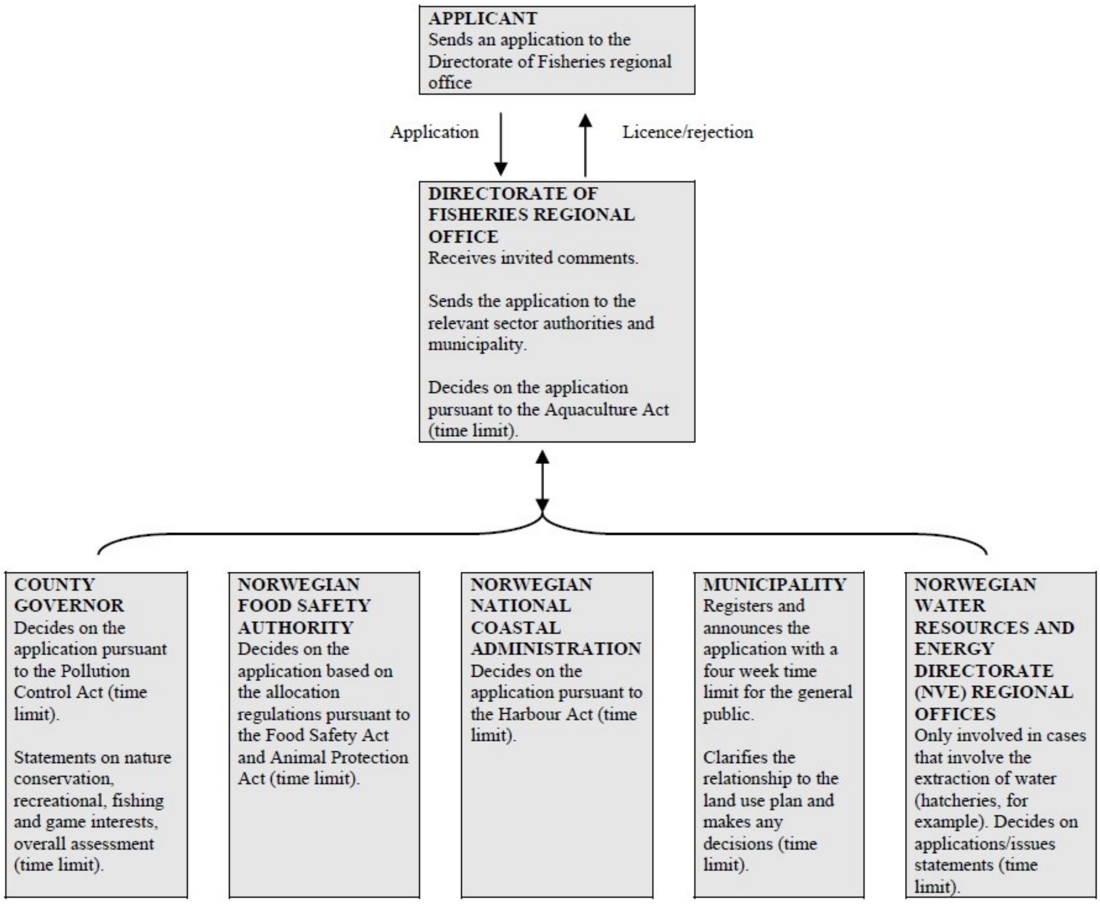
Source: ***Atlantic salmon and trout aquaculture statistic*, Directorate of Fisheries, 2020.**

APPENDIX 2 – Norwegian Exports (by country) of farmed Atlantic salmon in 2019



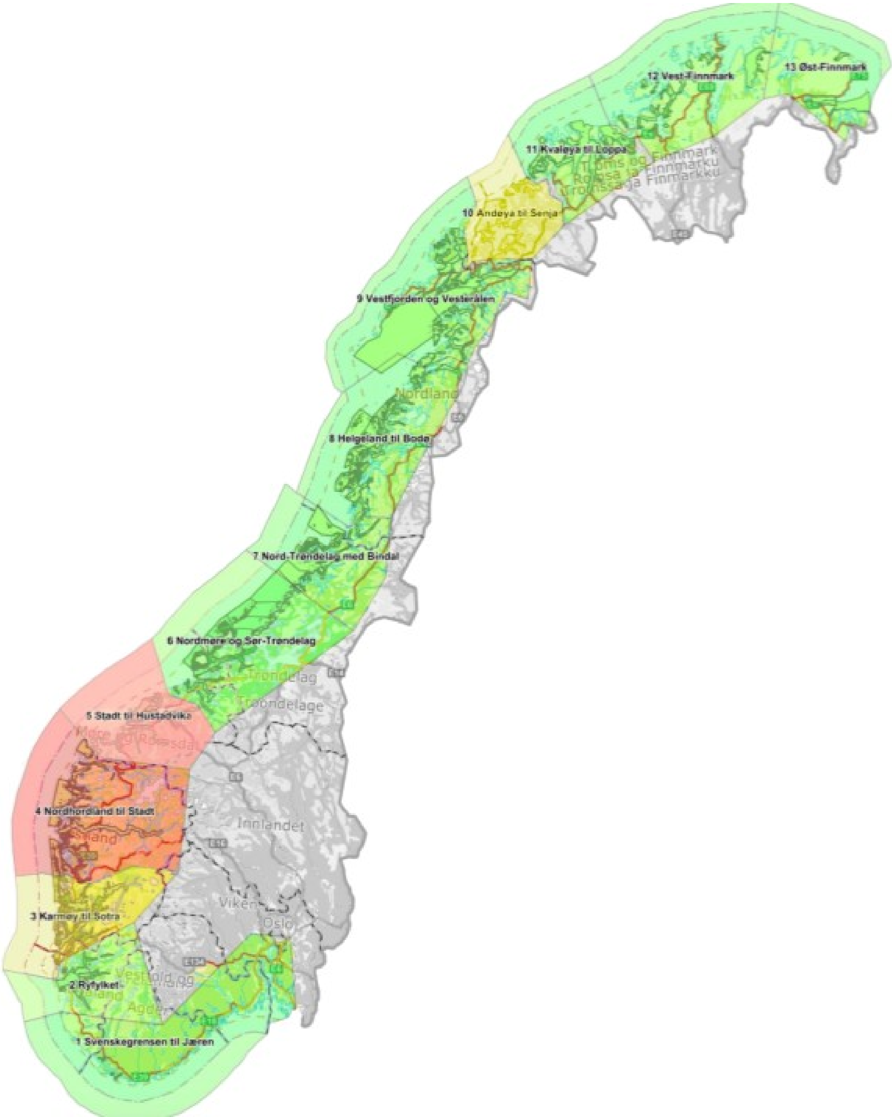
Source: Adapted from *the recipe for increasing seafood consumption,* Norwegian Seafood Council, 2021

APPENDIX 3 – Process to obtain an aquaculture production license in Norway.



Source: Adapted from *The Norwegian Aquaculture Act*, Ministry of Fisheries and Coastal Affairs, 2005.

APPENDIX 4 – Traffic light classification of production zones (2021)



Source: Adapted from *Marine protected areas,* Directorate of Fisheries, 2021.

APPENDIX 5 – Developmental Licenses awarded (2015 – 2021)

Company	Technology Used	Numbers of Licences	Production Capacity (MT)
Closed Containment Systems			
Leroy	Pipefarm	2	1,560
Måsøval Fiskeoppdrett	AquaFarm	4	3,120
Slaks	Fjordmax	6	4,680
Eide Fjordbuk	Salmon Zero	2	1,560
Reset Aqua	RAS Closed Frame	8	6,240
Nekst	Havlijen	2	1,560
Fish Globe	Fish-Globe	2	1,560
Mowi	Egg	6	4,680
Mowi	The Donut	2	1,560
Akvafuture (Akvadesign)	Not specified	2	1,560
Hydra Salmon	Not specified	4	3,120
		Total production capacity:	**31,200**
Semi Closed Containment Systems			
Midt-Norsk Havbruk	AquaTraz	4	3,120
Stadion Laks / Lingalaks,	Stadionbassenget	2	1,800
Nova Sea	Spidercage	4	3,120
Cermaq	iFarm	4	3,120
		Total production capacity:	**11,160**
Offshore Farms			
Norway Royal Salmon (NRS)	Arctic Offshore Farming	8	6,240
Nordlaks	Havfarmen	21	16,380
Atlantis Subsea Farming	Submersible Cage	1	780
Mariculture (Salmar)	Smart Fish Farm	8	6,240
		Total production capacity:	**29,640**

Source: *Futuristic Salmon Farming Projects*, Intrafish, 2020a.

APPENDIX 6 – Ongoing land-based salmon farming projects in Norway

Company	Production Capacity (MT)
Sande Aqua	33,000
Salmon Evolution*	28,800
Blom Fioskeoppdrett	20,000
Hardanger Storsmolt	20,000
OFS Andenes AS	20,000
OFS Maloy*	15,000
Stord Havbrukspark (Erko Seafood)	15,000
Gigante Salmon	13,800
Ecofisk	10,000
Kobbevik and Furuholmen Oppdrett (KFO)*	10,000
Anfjord Salmon*	10,000
Havlandet RAS*	10,000
Tomren Fish AS	10,000
Aquaculture Innovation AS	10,000
SalmoTerra*	8,000
Gaia Salmon AS	7,200
Losna Seafood*	7,000
Vadheim Akvapark AS	6,000
Fredrikstad Seafood AS	5,500
Smart Salmon AS	5,500
Salmo Farms*	5,000
Bulandet Miljøfisk	4,500
Nordic Aquafarms**	2,000
Green Atlantic / Havlandet RAS*	1,000
Potential Production License:	**277,300**
***Under construction or completed construction**	

Source: ***A particle List of Recent Land Based Salmonid Farms Globally*, Salmon Business, 2019.**

APPENDIX 7 -Sea lice R&D project funded by Research Council of Norway (2005 – 2021)

Year	Total (NOK)	Number of projects
2021	557,719,041.03	248
2020	478,224,009.08	287
2019	534,405,305.22	285
2018	534,502,923.85	291
2017	524,229,700.10	288
2016	483,532,661.25	249
2015	399,583,038.59	238
2014	354,095,613.49	205
2013	279,897,292.39	158
2012	277,355,009.98	162
2011	286,984,952.85	162
2010	305,669,710.06	151
2009	294,178,019.81	170
2008	242,663,667.40	169
2007	188,884,667.51	154
2006	144,241,335.09	143
2005	117,802,680.58	107
Total	**$6,003,969,628**	**3467**

Source: ***Statistics – Project Bank*****, Research Council of Norway, 2021**

APPENDIX 8 -Sea lice R&D project funded by The Fisheries and Aquaculture's Research Fund

(2005 – 2021)

Project Number	Project Title	Status	Budget
	1. Knowledge of Lice		
901565	Effects of infestation parameters on the interaction between salmon and salmon lice (INFEST)	Ongoing	9,072,000
901564	Interaction between salmon lice and salmon (ModuLus)	Ongoing	13,678,000
901539	Knowledge and experience mapping about Caligus elongatus (scabies) (Biscuits)	Completed	1,705,000
901424	Strategy Salmon lice 2017: Re-estimation of population model for salmon lice based on data from Rogaland	Completed	450,000
901283	Development of salmon lice at different temperatures and light (TEMPLUS)	Completed	5,292,000
901241	Mechanisms for the spread of salmon lice in farming and between wild and farmed salmonids (SMILA)	Completed	5,850,000
901108	Spread of salmon lice: Who infects whom?	Completed	1,798,000
901073	The influence of temperature on salmon lice larvae: Survival and infectivity	Completed	797,000
900970	Population model for salmon lice at cage and locality level	Completed	9,060,000
900950	Knowledge summary : Salmon lice and effects on sea trout	Completed	950,000
900932	The degree of returning salmon from smolt groups treated with antiparasitic agent compared to untreated smolt groups	Completed	2,440,000
900898	Significance of salmon lice from farmed salmon for wild salmon populations: Preliminary project	Completed	250,000
900790	Tracing of salmon lice origin: Wild salmon or farmed salmon as host fish	Completed	950,000
900607	Distribution of lice on salmon and significance for reproduction and control	Completed	108,000
900579	Evaluation (review) of the factual basis on the impact between farmed and wild salmon: Salmon lice, Nofima	Completed	310,000
900578	Evaluation (review) of the factual basis on the impact between farmed and wild salmon: Salmon lice and genetics, NIN	Completed	500,000
900555	The wild salmon project : Technical assistance in evaluation work	Completed	420,000
900400	The Salmon Louse Genome Sequencing Project: Part 1	Completed	3,075,000
552182	Sea Lice as a population regulating factor in Norwegian salmon	Completed	-
			56,705,000

	2. Registration and Counting of Lice		
901508	Fluorolice: Rapid fluorescence based identification of sea lice larvae in plankton samples	Ongoing	5,245,000
901411	Strategy Salmon lice 2017: Development of standardized counting methodology and calculation of lice occurrence	Completed	3,376,000
901302	Automatic classification and counting of salmon lice with underwater hyperspectral imaging (UHI): Phase 3	Completed	1,265,000
901212	Automatic classification and counting of salmon lice with underwater hyperspectral imaging: Continuation	Completed	2,416,000
901093	Classification and counting of salmon lice	Completed	1,455,000
901069	Automatic counting of salmon lice using optical detection	Completed	200,000
901044	Salmon lice counting: Improved methodology	Completed	1,470,000
900594	Evaluate and exploit automatically collected lice data & statistical evaluation of new counting method for salmon lice	Completed	700,000
			16,127,000

	3. Breeding and Genetics, Vaccine and Feed		
901631	Harnessing cross-species variation in sea lice resistance (CrispResist)	Ongoing	40,000,000
901569	Control of lice infestations in Atlantic salmon with immunoglobulin Y (IgY) -based interventions	Ongoing	5,300,000
901566	Host immunity and skin microbiome interplay: Importance for protection against sea lice infestation in Atlantic salmon	Ongoing	5,525,000
901509	System for dosing and distribution of the signal substance SNAP (Salmon Nest Appeasing Pheromine)	Ongoing	5,994,000
901511	Immunoglobulin Y (IgY) immunization of salmon against salmon lice	Completed	5,805,000
901510	Salmon lice vaccine: Production and testing of new vaccine candidates in small-scale trials	Completed	1,109,000
901464	Strategy Salmon lice 2017: Oxylipins - New solution to reduce lice infestation on salmon	Completed	2,300,000
901461	Strategy salmon lice 2017: Vaccine against salmon lice - laboratory test	Completed	1,611,000
901458	Preventive nutrition against lice on salmon	Completed	10,558,000
901457	Environmental regulation as a preventive principle against salmon lice	Completed	11,858,000
901413	Strengthening salmon's health for control of salmon lice	Completed	8,224,000
901068	Genetic resistance in salmon lice: Mapping of cage variation in genetic resistance, and how this affects the lice effect	Completed	4,638,000
900402	Interaction Between Fish and Salmon Louse: A Transcriptomic Study	Completed	240,000
900259	Towards Selection for Increased Resistance to the Salmon Louse in Atlantic Salmon	Completed	4,400,000
552312	Salmon louse vaccine: Identification and evaluation of novel antigens	Completed	-
532024	Breeding for a farmed salmon with greater resistance to salmon lice	Completed	850,000
			108,412,000

	4. Dissemination and Prevention		
901652	Effect and welfare when using cleaner fish and lice skirts (EFFECTIVE)	Ongoing	7,278,200
901650	Lice Control: Statistical modeling of control strategies for salmon lice	Ongoing	6,394,000
901567	AcuLice: Effect of complex acoustic sound image in the sea on salmon lice	Ongoing	2,800,000
901469	Smart-lighting and -feeding to enhance lice prevention and safeguard fish welfare: The Well	Completed	16,076,000
901456	Strategy Salmon lice 2017: Guide lights as prevention against salmon lice - demonstration experiments	Completed	5,055,000
901455	Strategy Salmon lice 2017: Preventive effect against salmon lice	Completed	6,770,000
901454	Strategy Salmon lice 2017: Validation of the Blue Lice system as a preventive method against salmon lice	Completed	2,093,000
901453	Strategy Salmon lice 2017: Documentation of lice protection with the “Mid-Norwegian ring”	Completed	6,688,000
901414	Strategy Salmon lice 2017: Uniform proactive lice strategy Rogaland	Completed	6,795,000
901405	Strategy Salmon lice 2017: What happens to lice skirts in currents and waves	Completed	1,151,000
901396	Strategy salmon lice 2017: Lice skirt as a non-medicinal method for prevention and control of salmon lice	Completed	6,850,000
901211	Utilization of skirts and snorkels for shielding farmed salmon against salmon lice: Seminar	Completed	300,000
901154	Can deep light and underwater feeding be used to reduce lice infestation?	Completed	2,560,000
901129	Knowledge status regarding the effect of ultrasound on salmon lice	Completed	150,000
901039	Flotation of salmon lice	Completed	683,000
900970	Population model for salmon lice at cage and locality level	Completed	9,060,000
900901	Validating the sea lice reproduction model	Completed	1,380,000
900884	Snorkelmerd: Production efficiency, behavior and welfare	Completed	4,976,000
900834	Lice skirt: Documentation of practical use and utility value	Completed	6,297,000
900815	Full-scale experiment with electric fence against salmon lice	Completed	4,000,000
900711	Permanent skirt for reducing lice infestation on salmon	Completed	11,925,000
900615	Salmon farming in closed facilities: Preliminary project	Completed	380,000
900606	BE salmon lice project: Phase I	Completed	3,400,000
			113,061,200

	5. Cleaner Fish / Lice Eating Fish		
901562	Program cleaner fish: Quality criteria for cleaner fish and the effect of broodstock nutrition (CleanLifeCycle)	Ongoing	7,000,000
901561	Program cleaning fish: Optimized initial feeding of cleaning fish (STARTRENS)	Ongoing	8,782,000
901418	Program cleaner fish: Reproductive biology in roe biscuits: A key to a successful breeding program (CYCLOBREED)	Ongoing	16,625,000
901331	Program cleaner fish: Nutritional needs and feeding for optimal health and survival of cleaner fish	Ongoing	22,915,000
901264	Experiments with dip and stab vaccination of roe biscuits in the infection cell and field experiments.	Completed	1,840,000
901234	Program cleaner fish: Infection-free roe biscuit roe	Completed	1,756,000
901174	Program cleaning fish: Water quality and starter feeding for roe biscuits	Completed	1,000,000
901135	Program cleaner fish: Mapping of the gilthead genome	Completed	427,000
900997	Program cleaner fish: Rock gilt broodstock	Completed	2,070,000
900977	Program cleaner fish: Broodstock of roe deer	Completed	5,827,000
900829	Comprehensive concept for sorting and logistics of roe deer fry	Completed	1,624,000
900609	Stocks and catch quality of wrasse	Completed	7,493,761
900554	Production of gilthead seabream (LeppeProd)	Completed	34,105,000
900482	Optimized production, nutrition and use of the cleanerfish Ballan wrasse (Labrus bergylta)	Completed	12,015,000
901647	Effective and sound use of cleaner fish: A campaign for best practice use of cleaner fish	Ongoing	3,569,000
901563	Program cleaner fish: Environment and feeding for optimal health and survival of cleaner fish in cages (OptiRens)	Ongoing	4,980,000
901560	Program cleaner fish: Recapture, stunning, killing and reuse of cleaner fish (CLEANCATCH)	Ongoing	6,967,000
901468	Program cleaner fish: Uptake and excretion of antibacterial agents from plasma and tissue in roe deer	Completed	1,242,000
901426	Program cleaner fish: Tolerance for transport stress and environmental transitions in gilthead seabream and roe deer	Completed	1,670,000
901320	Program cleaner fish: Parasitic infection in roe deer: Nucleospora cyclopteri	Completed	2,352,000
901258	Program cleaner fish: Update of cleaner fish guides	Completed	375,000
901235	Program cleaner fish: Capture, killing and facilitation for reuse of cleaner fish.	Completed	2,495,450
901188	Program cleaner fish: Investigation of mortality in connection with acute mortality / increased mortality in roe deer in 2	Completed	650,050
901158	Program cleaner fish: Development of transport and reception procedures for roe biscuits	Completed	2,482,000
901152	Program cleaner fish: Cataract in roe deer	Completed	1,581,500
901146	Program cleaner fish: Artificial light and cleaner fish	Completed	3,576,000
901136	Program cleaner fish: Welfare of cleaner fish - operational indicators (RENSVEL)	Completed	14,100,000
901120	Analysis of disease-related risk associated with the use of wild-caught and farmed cleaner fish for control of salmon li	Completed	1,184,000
900979	Program cleaner fish: Use of roe biscuits in cages	Completed	13,012,000
900978	Program cleaner fish: Behavior and species interaction in salmon cages	Completed	3,755,000
900976	Program cleaner fish: Identify the possibilities for profitable after-use	Completed	370,000
900831	Develop knowledge of how best to get the cleaner fish to survive the winter in the salmon cages	Completed	775,000
900818	Cleaning fish: Causes of loss and preventive measures	Completed	11,376,000
			199,991,761

	6. Non - Drug Based Delicing		
901649	Objective documentation and best practices for improving thermal de-lice (TermVel)	Ongoing	11,846,000
901450	Development of a resource- and environmentally friendly method for collecting lice during de-lice salmon	Ongoing	3,679,000
901400	Slaughter of salmon: Development of new technology for handling fish for slaughter (STRESSLESS)	Ongoing	26,000,000
901488	Cold water as a de- lice remedy ? Effect on salmon lice and salmon welfare and mortality	Completed	750,000
901460	Strategy salmon lice 2017: Potential use of lighting technology for sterilization of salmon lice eggs in cages	Completed	1,980,000
901438	Salmon lice sensitivity to fresh water and hot water	Completed	4,901,000
901397	Standardized methodology for qualification of mechanical de-lice systems (KVALISYS)	Completed	3,940,000
901342	Waterfall for salmon lice control: Phase 2	Completed	1,235,000
901329	Study of fish welfare using HydroLicer	Completed	2,329,000
901296	Best Practice for Drug-Free Lice Control (FREE)	Completed	4,123,000
901243	Salmon lice: Drug-free control by combined measures	Completed	13,204,000
901233	Waterfall for salmon lice control	Completed	646,792
901208	Freshwater de-lice and stress effects on lice (OSMO lice)	Completed	1,496,000
901192	Field test of ultrasound against salmon lice	Completed	206,000
901187	Ultrasound against salmon lice: Controlled testing of surcharges on salmon in tanks	Completed	802,000
901160	Ultrasound against salmon lice: "Proof of concept" - controlled testing of effect directly on salmon lice	Completed	1,335,000
901153	Lice flushing: Full-scale documentation of the effect on salmon lice and fish welfare	Completed	907,000
901021	Freshwater against salmon lice: Mechanism studies	Completed	152,000
901010	Temperate water against salmon lice - documentation studies	Completed	831,000
901006	Use of fresh water for de-lice in well boats	Completed	1,500,000
900436	Mechanical removal of salmon lice	Completed	224,000
			81,862,792

	7. Drug Based Delicing		
901558	Cleansulf: Neutralization of hydrogen peroxide using e.g. sodium sulfite and environmental risk assessment of the process	Ongoing	2,957,000
901651	New method for reducing salmon lice using chitinolytic enzymes: Verification experiments	Completed	630,000
901249	Environmental risk due to the use of hydrogen peroxide (H_2O_2) in farming	Completed	2,200,00
901226	Dilution Study : Hydrogen Peroxide	Completed	770,000
901150	De- lice with hydrogen peroxide and environmental factors	Completed	1,630,000
901068	Genetic resistance in salmon lice: Mapping of cage variation in genetic resistance, and how this affects the lice effect	Completed	4,638,000
901011	Model experiment with cloth-based de-lice	Completed	2,489,000
900834	Lice skirt: Documentation of practical use and utility value	Completed	6,297,000
900466	A multidisciplinary project to improve bathing treatment against salmon lice (Topilouse)	Completed	8,866,500
			19,411,000
Total Number of Projects:	**129**		
Total Funding for salmon Lice related projects:	**NOK 595,570,753**		
Source: The Fisheries and Aquaculture Research Funding (FHF)			

Source: ***Salmon Lice*****, The Fisheries and Aquaculture Research Funding, 2021.**