Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Economics and Management
Dept. of Industrial Economics and Technology Management

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Financial Implications of Biodiversity Conservation in Global Aquaculture Companies

Master's thesis in Industrial Economics and Technology Management
Supervisor: Rodrigo Graca
Co-supervisor: dr. Morten Risstad and dr. Malvina Marchese
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Abstract

This thesis investigates how biodiversity affects firms' financial performance within the salmon-farming industry. The influence of biodiversity on financial performance is increasingly being acknowledged. Nevertheless, a tangible gap persists in the academic literature regarding this relationship. Utilizing a novel panel dataset compiled from 41 salmon farming companies spanning from 2014 to 2021, this research integrates multiple sources and industry-specific variables to create a unique and international data sample. Our research is twofold. First, we apply a difference-in-differences estimator, defining treatment and control groups, to ascertain the effects of Norway's Traffic Light System – a policy targeting biodiversity – on firms' Return on Assets (ROA). The evidence suggest that the Traffic Light regulation has had a negative effect on financial performance for the companies affected. Second, we use a well-developed dynamic panel generalized method of moments (GMM) estimator to explore the relationship between specific biodiversity variables (sea lice prevalence, sea lice treatments, and escapes) and ROA. The estimator incorporates the dynamic nature of financial performance to address unobserved heterogeneity and endogeneity issues. We find that sea lice treatments and escaped salmon have a negative impact on ROA. However, an alternative treatment method using Hydrogen Peroxide (H_2O_2) and sea lice prevalence have a positive impact on ROA. Overall, our research contributes to the growing body of literature on ESG and financial performance and shed light on the intricate interdependencies between biodiversity, regulatory practices, and financial performance in the context of the global salmon farming industry.

Preface

This thesis represents the culmination of our path towards attaining a Master of Science (MSc) degree at the Norwegian University of Science and Technology (NTNU), with a specialization within Financial Engineering at the Department of Industrial Economics and Technology Management. Work on this thesis was conducted from January to June in 2023.

In our thesis, we conduct a thorough investigation of the relationship between sustainable finance, biodiversity, and aquaculture, looking into the potential impact that policy changes and particular biodiversity impact factors may have on the financial performance of aquaculture businesses. Policymakers, environmentalists, financial analysts, and other stakeholders with an interest in the relationship between sustainable practices, biodiversity conservation, and the economic viability of aquaculture enterprises should find this study relevant.

We want to extend our gratitude to our supervisors, Rodrigo Graca, Morten Risstad and Malvina Marchese, for guidance in academic writing, help with the methodology, and interesting discussions during the process. They have been available throughout the semester and provided detailed feedback on our work and process. We are very grateful.

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1 Introduction

Biodiversity refers to the variability among living organisms within and across ecosystems (CBD, 2007). It constitutes a life-essential network that offers critical ecological services from stabilising climates to providing our food and water resources, thus being critical to the prosperity of our global society (Rockström et al., 2009). However, humanity is facing a biodiversity crisis. Currently, the animal populations correspond to only 31% of its numbers in 1970 (WWF, 2022). In addition, up to 1 million species, 25% of animals and plants catalogued, are at risk of extinction. These numbers make this the sixth major extinction event in Earth's history (IPBES, 2019; Rockström et al., 2009). Biodiversity loss is emerging as a pressing issue for decision-makers worldwide. This concerning trend has led the World Economic Forum to consecutively identify decline in biodiversity as one of the major risks for the next decade in its most recent annual reports (World Economic Forum, 2023, 2022, 2021). This environmental problem entails significant economic risks (Dasgupta, 2021). Companies are increasingly confronted with the risks of operational disruptions and reputational damage resulting from environmental degradation (CBD, 2020). As such, confronting biodiversity loss is not only an ecological imperative but also vital for sustained economic growth. In this dissertation, we shed light on the complexities of biodiversity, deploying empirical tests to dissect the influence of biodiversity-specific factors and regulatory mechanisms on financial performance in the salmon aquaculture sector. We focus on salmon farming due to its circular dependence on biodiversity: the industry's success is critically intertwined with the health and diversity of the surrounding ecosystems it depends upon, yet its operations pose serious threats to these very ecosystems.

The last decade has been marked by the incorporation of Environmental, Social and Governance (ESG) criteria into financial analysis (Yu et al., 2020). The relationship between ESG and financial performance has been extensively studied (Stern, 2021; Friede et al., 2015). Nevertheless, biodiversity remains an undervalued aspect and a "blind spot" in many investment strategies (Schwartzkopff & White, 2023; Marsh, 2022). Even those who are considered to be the best ESG managers fail to adequately deal with biodiversity risks in their investment portfolios (ShareAction, 2023). ShareAction (2023) highlights the urgent need for investment managers to prioritize biodiversity in light of the COP15[1] agreement, which places biodiversity on par with the Paris climate treaty in terms of significance. Indeed, policies such as the EU taxonomy[2] are set to shift the regulatory landscape towards stricter environmental standards. Still, there is currently a glaring lack of action among asset managers in addressing biodiversity risks (EU, 2021). To effectively tackle environmental challenges such as biodiversity, establishing supportive policies and developing financial mechanisms that incentivize sustainable investments are crucial (Lombrana et al., 2022).

The increase in fish consumption has been twice the population growth rate since 1961 (FAO, 2022). Human activities, such as fishing, have resulted in large and widespread damage to the marine ecosystems (IPBES, 2019). According to UNCTAD (2018), nearly 90% of the world's marine fish populations are either overexploited or depleted. In this scenario, the sustainability of industries like aquaculture becomes paramount by combating this issue (EIIT, 2021). There is an indication that aquaculture will be included in the following extension of the EU taxonomy (Ahlstrand, 2021; European Commission, 2021). Both Ahlstrand (2021) and European Commission (2021) highlight the importance of the fisheries and aquaculture sector in achieving the FAO's[3] objective of eradicating hunger and malnutrition worldwide. Despite the aforementioned merits of aquaculture, the expansion of fish farming, particularly salmon farming, raises concerns about its environmental impact. In the aquaculture sector, salmon farming is particularly relevant due to its high production volumes, making it a key area of focus in the discussion about environmental impacts and sustainability.

[1] COP15 stands for the Conference of the Parties to the United Nations (UN) Convention on Biological Diversity's (CBD) 15th meeting. The CBD is a historical international agreement committed to protecting animal and plant species and guaranteeing that natural resources are utilised responsibly.

[2] EU taxonomy establishes a structured system for defining economic activities as deemed "green" or "sustainable" (EU, 2021). The primary objective of this regulatory framework is to guide the EU towards a climate-neutral economy by the year 2050.

[3] FAO: Food and Agriculture Organization of the United Nations.

Salmon farms can negatively affect surrounding ecosystems due to the high concentrations of fish, waste, and chemicals. This industry affects the coastal fisheries, the sea floor and the wild salmon population (Olaussen, 2018). Some major threats to wild salmon species are escapes from fish farms and elevated densities of sea lice, which is a fish parasite (Forseth et al., 2017; Thorsdad & Forseth, 2017). These problems also pose noteworthy profitability implications for the farmers, in loss of future sales due to escaped biomass and increased costs from managing sea lice infestations and recapturing escaped fish (Lerøy Seafood Group, 2021; Abolofia et al., 2017). There is an overall understanding of these direct costs and environmental impacts, but there is a gap in the literature regarding the effects of biodiversity changes on the financial performance of companies in the salmon aquaculture industry.

Numerous countries have instituted regulations and incentives to promote more environmentally responsible practices to mitigate the adverse impacts of salmon farming on biodiversity. In Norway, the *Traffic Light System*[4] is implemented to manage the environmental impact of salmon farming, in which the expansion of farming is directly tied to the local environmental conditions (Norsk Fisk, 2022). Similarly, the Faroe Islands have enacted regulatory measures to ensure sustainable salmon production (FaroeIslands, 2019). These measures include regulations on fish density, feed composition, and disease control, which significantly affect the operating environment for salmon farmers. These legislative efforts align with global commitments such as those established in the Convention on Biological Diversity at COP15. This international focus on sustainable practices, combined with heightened public awareness and consumer demand for sustainably produced food, will continue shaping the evolution of the salmon farming industry (Schneider, 2023). Nevertheless, there is limited knowledge of how biodiversity-related regulatory changes directly influence the profitability of companies in the salmon farming industry.

We contribute to the branch of literature investigating the interplay between biodiversity, regulatory frameworks, and the financial performance of firms. By employing a difference-in-differences (DiD) approach, we examine the effect of Norway's policy change relating to biodiversity conservation (the *Traffic Light System*) and how its implementation impacts the returns of Norwegian companies in comparison to some of their counterparts in Chile, the Faroe Islands, New Zealand, and Australia, which are not subject to this policy. We find that introducing the *Traffic Light System* decreases the profitability of companies. The empirical results suggest that the biodiversity conservation regulatory framework inhibits financial performance in the short-term. We demonstrate the nuanced balance required to enact policy changes that, while potentially leading to short-term profitability declines, encourage industry innovation and enhance biodiversity preservation. These findings are relevant to several different stakeholders in the aquaculture industry. For investors, these findings may serve as an indicator of risk related to investment decisions in aquaculture companies. Additionally, our findings are indicative for policymakers who can utilize this information to weigh trade-offs between environmental and economical concerns and decide wisely on the creation and application of such legislation.

To examine the relationship between biodiversity factors and financial performance, we employ a dynamic one- and two-step System Generalized Method of Moments (GMM) estimator. Utilizing the dynamic panel GMM estimator, we provide a deeper understanding of the interplay between specific biodiversity factors in aquaculture and financial performance and its evolution over time. Our study employs a novel dataset of companies from Chile, Norway, the Faroe Islands, Australia, and New Zealand. We consider material biodiversity-related factors in the industry: the occurrence of sea lice, the amount of medicine used in lice treatments via feed- and bath treatments, the usage of Hydrogen Peroxide (H_2O_2), and the number of escaped salmon. Our results show that a high number of escapes and a high usage of chemicals in lice treatments harm financial returns. Moreover, we uncover that H_2O_2 and elevated numbers of sea lice positively impact returns. Concerning sea lice, we contend that reporting bias might play a substantial role in the apparent positive interplay observed. In sum, our results highlight the potential for economic advantage in adhering to sustainable practices and risk management strategies concerning biodiversity. In doing so, they enable stakeholders and investors to make the connection where economic profitability can coexist with environmental responsibility.

[4]The Traffic Light System: Measuring the sea lice prevalence on wild salmon in Norway. New regulation in 2017 defines the maximum amount of salmon produced in different production areas.

Furthermore, we add to another branch of literature regarding specific biodiversity impact indicators that serve as a proxy for biodiversity performance in the salmon farming industry. Non-financial indicators are becoming increasingly more important for investors, financial institutions, and company managers (Biodiversity Indicators Partnership, 2011; Addison et al., 2018). Although numerous researchers have developed biodiversity indicators, the International Union for Conservation of Nature (IUCN) alerts to a lack of indicators specifically designed to measure biodiversity impacts at the corporate level (Addison et al., 2018). Developing such indicators enables a more effective assessment of corporate biodiversity performance. In synthesizing these points, our study situates itself within the evolving dialogue of sustainable business practices. Our approach to establishing critical biodiversity impact variables and objectively assessing company-specific impacts forms a critical step in bridging the current gap in biodiversity indicators at the corporate level. In crafting a novel dataset based on publicly available metrics, we provide a valuable tool to evaluate performance on biodiversity issues within the aquaculture industry.

The remainder of the thesis is organized as follows: Chapter 2 presents an overview of relevant topics; Chapter 3 provides a comprehensive examination of the broad literature; Chapter 4 describes the data and variables; Chapter 5 present the methodology, followed by the results and discussion of our findings in Chapter 6. Finally, Chapter 7 provides a conclusion to our thesis.

2 Background

The following chapter presents key topics such as socially responsible investments, ESG, and aquaculture. Here, a summary of subjects relevant to our thesis is introduced. We assess both historical and contemporary trends.

2.1 Salmon Farming Industry

According to UNCTAD (2018), almost 90% of the world's marine fish populations are either overexploited or depleted. Here, aquaculture development has become an important remedy for widespread overfishing. Through the production of fish, shellfish, algae, and other species in various aquatic settings, the aquaculture sector produces animal protein without resorting to excessive fishing. While fisheries have been suffering from overcapacity and lax regulatory systems, aquaculture has progressively been able to boost output. Figure 2.1 illustrates the development of the fishing industry. Over the period from 1961 to 2019, the worldwide consumption of aquatic foods rose at an average yearly rate of 3.0 percent. In 2020, the global contributions of capture fisheries and aquaculture stood at 90 million tonnes (51 percent of total production) and 88 million tonnes (49 percent of total production), respectively. According to the most recent "The Status of World Fisheries and Aquaculture" report from the UN, aquaculture production is estimated to surpass the 100 million metric tons threshold in 2027 (FAO, 2022).

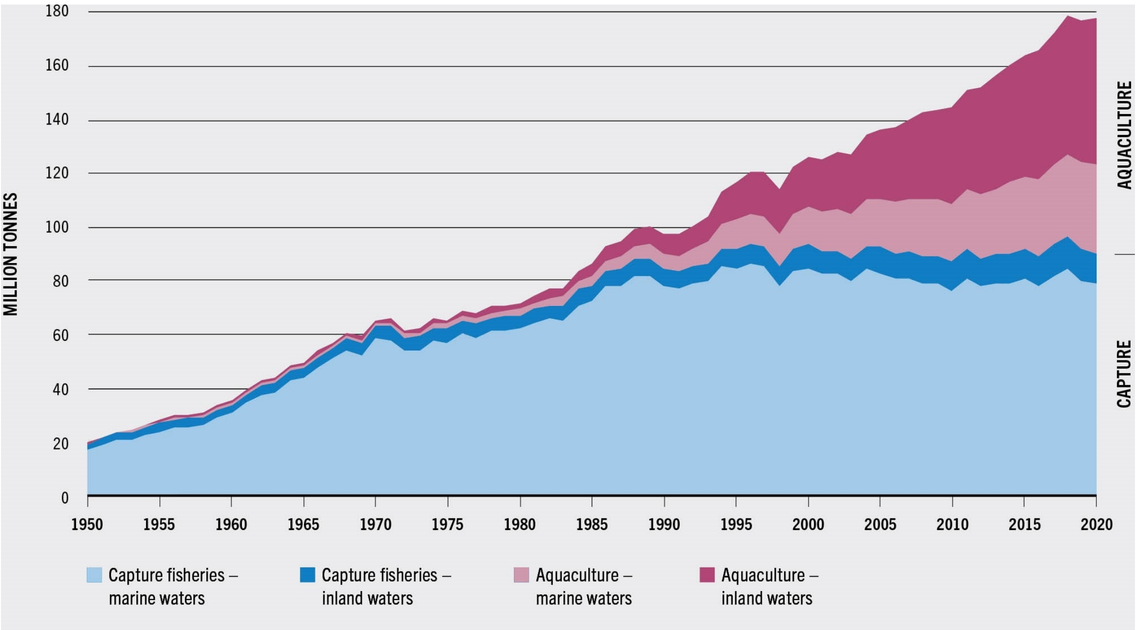

Figure 2.1: Historical production of aquaculture and capture fisheries. Source: FAO (2022).

While global aquaculture, growing at an annual rate of 3 percent from 1961 to 2021, includes a variety of species, salmon's growth trajectory stands out. As one of the first species domesticated for aquaculture, salmon has become one of the most intensively farmed fish globally. Notably, in Norway, the largest global provider of farmed Atlantic salmon, the industry experienced an annual growth rate of 6.5 percent between 1997 and 2017 (Misund, 2022). The salmon farming industry's advancement has spurred improvements in feed, breeding, disease control, and environmental management, innovations that have benefitted other species and aquaculture systems. By 2017, aquaculture's impact had expanded to account for approximately 17% of the animal protein consumed worldwide (UNCTAD, 2018).

Turning to specific national contributors, three of the largest producers of farmed salmon worldwide (Chile, Norway, and the Faroe Islands) account for approximately 83% of global salmon production, as depicted in Figure 2.2. While emerging players such as Australia, the United States and New Zealand are making contributions to global production, the majority of farmed salmon production remains concentrated in these dominant countries.

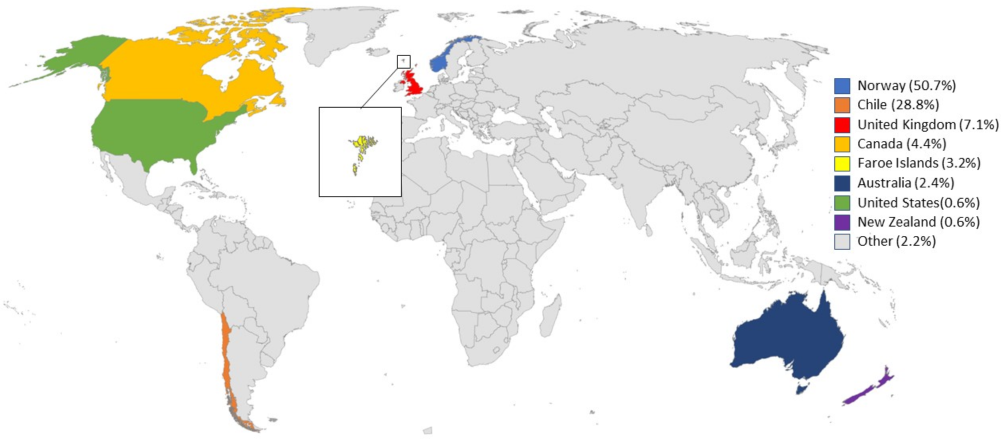

Figure 2.2: Global distribution of farmed salmon production by percentage in 2020. Measurement in tonnes of live weight. The species included are Atlantic salmon and Chinook King salmon (New Zealand) in both marine and freshwater. Adapted from: FAO and UN (2022).

The salmon farming industry is subject to varying degrees of policy and regulation across different countries to ensure sustainable practices. It is essential to recognize that sustainable and responsible farming practices encompass not just financial concerns and emission reductions, but also considerations of biodiversity, social impacts, and reporting transparency. Norway, for instance, enforces some of the most stringent regulations in the industry, including limits on fish density and the use of antibiotics (Norsk Fisk, 2022; Norwegian Medical Control Authority, 2000). One of the most pressing challenges faced by the salmon farming industry is sea lice infestation, which can negatively impact fish health and the surrounding ecosystem (Grefsrud et al., 2022). Norway has implemented a "Traffic Light System" to address one of the most pressing challenges faced by the salmon farming industry, namely sea lice infestation. By using a color-coded classification to indicate the severity of sea lice infestations in different regions. This system encourages the industry to adopt more sustainable practices by limiting production growth in areas with high infestation rates while allowing expansion in regions with low sea lice presence.

In 2003, the Faroe Islands implemented a comprehensive and strict aquaculture veterinarian regulatory regime, aiming to create the most sustainable salmon production environment, ensure fish welfare, and eliminate the use of antibiotics (Stockholm Resilience Centre, 2019; FaroeIslands, 2019). This reform in the Faroese aquaculture sector had a substantial positive effect on the mortality rate of farmed Atlantic salmon, which decreased from 28% in 2002 to less than 3% in 2005 (ICES, 2022). During the first decade following the reform, the Faroes ecoregion consistently exhibited lower mortality rates for farmed Atlantic salmon compared to several other salmon-producing countries. However, the fish mortality rate has gradually increased since 2005 with the introduction of mechanical and thermal lice treatments as well as moving more of their production offshore. Despite this increase, the Faroe Islands' industry still maintains one of the lowest mortality rates of 10%-15% worldwide (ICES, 2022). In contrast, Chile's less regulated industry has raised concerns regarding the environmental impact of salmon farming due to the over-usage of antibiotics and the risk of eutrophication (Chilean Government, 2022; Molinari, 2022a).

Australia and New Zealand have established regulations to ensure environmental sustainability within the industry. Nevertheless, Australia's largest salmon company, Tassal, faced controversy for using more than two tonnes of antibiotics at two of its fish farms in early 2022 to treat outbreaks of vibrio, a bacterium that can cause high mortality rates (Burton, 2023). Tassal sought to block the release of monitoring reports submitted to the state's Environment Protection Agency (EPA), arguing that the information should be considered commercial-in-confidence (Burton, 2023). Additionally, biomass limits in the context of salmon farming were closely examined, as excessive levels of dissolved nitrogen and nutrients from fish farms have been implicated in the proliferation of green algae in Tasmanian waterways. The dispute with Tassal over the publication of these reports raised concerns about transparency in the industry and the increasing use of antibiotics despite the availability of vaccines for salmon (Ebert, 2022). Going forward, the government has implemented a 10-year plan to reset the industry and promote more sustainable practises (Barnett, 2021). Despite the varying levels of regulation and controversy, all countries are actively working towards promoting salmon farming practices that prioritize environmental sustainability, social responsibility, and transparency.

2.2 Aquaculture and the Importance of Biodiversity

In recent years, the business world has witnessed a growing emphasis on ESG factors (Atz et al., 2023). These non-financial factors offer complementary methods for evaluating a company by encompassing its performance across three critical dimensions: environmental, social and ethical practices, and governance structure. Due to rising awareness of the social and environmental impact of business and knowledge of the long-term advantages of sustainable practices, there has been a growth in sustainable investments in recent years. As depicted in Figure 2.3, there has been a significant influx of investments into sustainable funds over the past decade. Nevertheless, the UN Biodiversity Conference (COP15) in Montreal, Canada, in December 2022, illustrates that biodiversity has been overlooked in ESG risks. The conference discussed adopting a global biodiversity framework to counteract biodiversity loss. The current state of the world's ecosystems is threatened by biodiversity loss, which is greatly influenced by climate change. According to a recent study by WWF (2022), wildlife numbers have decreased by 69% since 1970. Rockström et al. (2009) emphasizes the significance of biodiversity as a crucial aspect of the environment for the continued existence of the human species. The World Economic Forum (2023) ranks "biodiversity loss" as one of the top three risks in their annual risk report due to its overarching effects. The current rate of biodiversity extinction serves as a stark reminder that humanity still has a long way to go before achieving a level of growth that our planet is able to sustain.

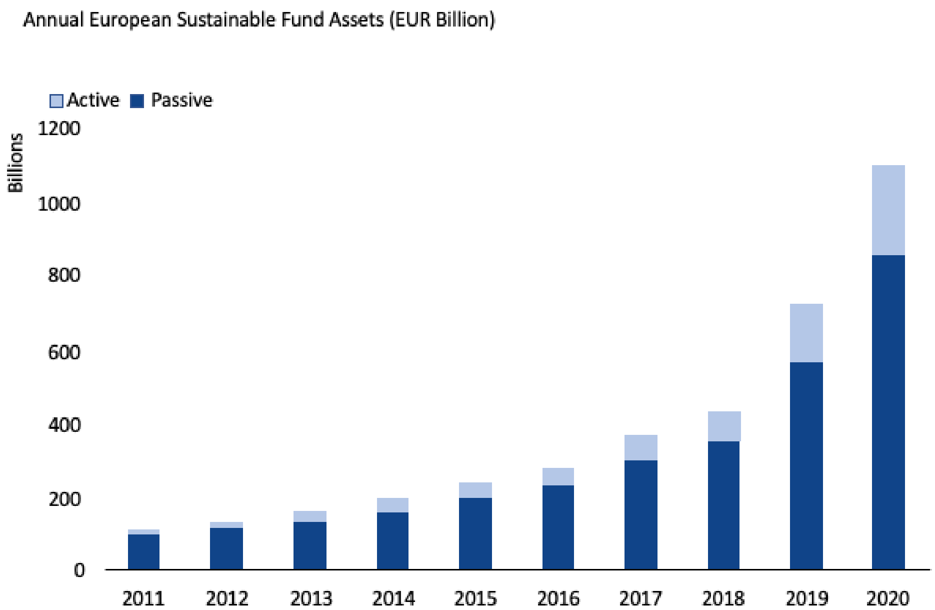

Figure 2.3: Annual European Sustainable Fund Assets (EUR Billion). Adapted from: Hortense Bioy, CFA (2021).

Farmed salmon is a leader in material sustainability metrics for efficient and sustainable production compared to other animal protein producers. As seen in Figure 2.4 and Figure 2.5 some common sustainability metrics for protein producers are listed, with salmon farming scoring high on metrics such as carbon footprint and protein retention (Global Salmon Initiative, 2022a). The Coller FAIRR Protein Producer Index evaluates how the world's largest animal protein producers handle significant ESG risks, with aquaculture companies, such as Mowi, Grieg Seafood, and Lerøy Seafood, being the top performers compared to traditional protein producers. However, there is a concern as to how the industry affects the surrounding biodiversity. This thesis addresses this issue by including biodiversity factors to capture the adverse effects on the aquaculture industry. We draw on Grefsrud et al. (2022)'s risk report for assessing relevant issues from a biological standpoint, recognizing that geographical differences between locations may influence the industry's impact on biodiversity.

	Farmed Atlantic Salmon	Chicken	Pork	Beef	Lamb
Global Production	2.7 million	118.0 million	110.1 million	68.3 million	9.9 million
Carbon Footprint*	0.60	0.88	1.30	5.92	No Data
Protein Retention	28%	37%	21%	14%	No Data
Edible Yield	68%	46%	52%	No Data	38%

Figure 2.4: Overview of material sustainability metrics of different animal protein sources. Global production is measured in tonnes. The carbon footprint of a product is calculated as the number of kilograms of carbon dioxide equivalent ($kgCO_2eq$) in each average serving (40 g) of edible protein. An estimate of a product's carbon footprint captures all greenhouse gas emissions, both directly and indirectly, during production (Global Salmon Initiative, 2022a). Protein retention is the term used to indicate the increase in edible protein as a percentage of total protein consumption. The proportion is computed as follows: grams of protein in the edible portion / grams of protein in the feed. Edible yield is calculated by dividing edible meat by total body weight. *The carbon footprint measurement is an estimate for various sources of farmed salmon e.g. Atlantic salmon and Chinook (Spring/King) salmon. Adapted from: Global Salmon Initiative (2022a).

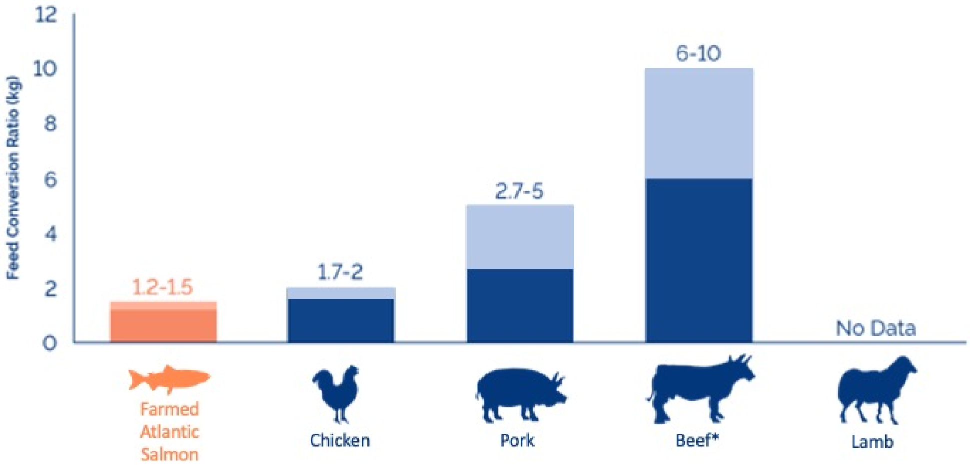

Figure 2.5: Overview of the Feed Conversion Rate (FCR) of various animal protein sources. The FCR measures the efficacy of various protein production techniques. It indicates the proportions of which the animal's bodyweight must rise by 1 kg for every kilogram of feed consumed. A lower FCR indicates more effective utilization of feed supplies (Global Salmon Initiative, 2022a). The ranges illustrate how the feed conversion ratios are impacted by the varying feed costs for the sectors mentioned above. *The use of various types of feed results in a wider variation in the FCR of beef production. Adapted from: Global Salmon Initiative (2022b).

Beveridge et al. (1994) identifies three key mechanisms through which aquaculture affects biodiversity. The first factor relates to the direct usage of natural resources. Here, resources being both on land and in the ocean, including feed, building supplies, etc. Second, the process of transformation within the aquaculture sector itself. This encompasses all of the various activities and procedures involved in raising aquatic animals for food, such as breeding, hatching, feeding, growing, and harvesting. The third factor is the production of waste related to the operations in the industry (e.g. food wastes, chemicals, excrements). Diana (2009) highlights several risks that are related to aquaculture and how it affects biodiversity. Some of the main threats are eutrophication caused by effluent discharge, the possibility that escaped fish would genetically modify local species, and the transmission of diseases to wild fish populations.

Following the growth of the industry, increased regulatory attention draws emphasis on reporting and sustainable management. This attention has been driven in part by the critical points raised by Diana (2009), which underscore the possible biodiversity risks associated with salmon farming. These points continue to be relevant as annual reports and recent studies such as Grefsrud et al. (2022), use these metrics as important KPIs in order to assess risks related to aquaculture. Although there has been progress in this area, more research is still required to fully understand how to evaluate the potential effects aquaculture has on biodiversity. In our work, we capture critical industry-specific dimensions and contribute to a novel field investigating the relationship between biodiversity impact variables and the financial performance of salmon farming companies on an international scale.

2.3 Risk Assessment: Biodiversity Impact Variables

Given the novelty of the field concerned with biodiversity impacts in aquaculture, we utilized studies by Beveridge et al. (1994) and Diana (2009) as guidance for which biodiversity impact variables to include in our study. These studies are some of the main references regarding aquaculture and biodiversity and highlight the threats that aquaculture poses towards biodiversity. Due to the leading position of Norway in the salmon aquaculture market, as shown in Figure 2.2, we also consider the annual "Risk report on Norwegian Salmon farming" by Grefsrud et al. (2022) in the selection of what biodiversity impact variables to include.

The salmon farming industry is divided into a number of separate stages, each with its own unique challenges. These operations begin with the spawn-phase of the fish, progress to the smolt-phase, and continue with the growth process of the fish until they reach a mature stage, at which point they are harvested and further processed for market distribution. Using publicly available company data and the report by Grefsrud et al. (2022) as a guide, we have identified some of the factors that have the greatest impact on biodiversity within the salmon farming industry. As seen in Figure 2.6, we focus on the growth phase of the salmon farming operations. Evaluation concentrates on this specific phase in particular as this is where the primary direct impact variables on biodiversity have been identified. It is important to note that upstream supply-chain activities (e.g., fish feed) and downstream processes related to transportation and processing (e.g., emissions) are not within the purview of our research.

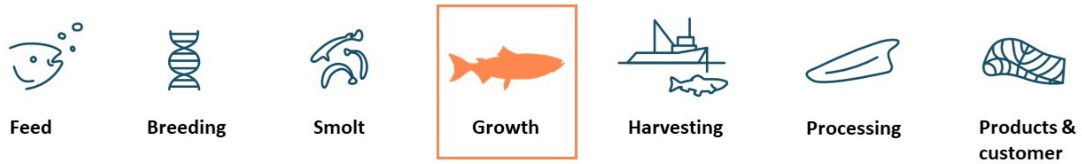

Figure 2.6: Overview of the different stages in the salmon farming value chain. Adapted from: Mowi (2022).

Our study specifically targets variables with a direct effect on biodiversity. Here, sea lice, lice treatments, and escapes are assessed as major threats to biodiversity in salmon farming. Other aspects such as eutrophication and waste production are also material risks to biodiversity. However, the latter variables have been omitted in our study based on the lack of company data on an international level. As an extension of our study, these are other factors that can be studied in future work. We present potential extensions of our work in Chapter 7.

Considering the intricacies of these biodiversity issues, we determine if there are any financial implications for the salmon farming companies featured in our study. To accomplish this, we will examine the following three direct impact indicators that are identified as the most relevant according to the literature Beveridge et al. (1994); Diana (2009): *Lice Prevalence*, *Lice Treatments*, and *Escapes*.

2.3.1 Lice Prevalence

A major hardship in the salmon farming industry is the salmon lice (Lepeophtheirus salmonis) which infest both farmed and wild salmon populations, leading to both economic and ecological issues. As presented in Grefsrud et al. (2022), salmon lice pose a credible threat to the biodiversity of marine ecosystems. Salmon lice are parasites that feed of the skin, blood and mucus of the fish which compromises the health and reproductive capabilities of their hosts. Furthermore, they can lead to infection and other diseases that decrease the lifetime of the fish. In areas with high concentrations, there can be a "spillover-effect", where the parasites are able to transfer to surrounding ecosystems. Since lice can be transmitted from farmed to wild salmon, lice threaten biodiversity and the long-term sustainability of wild populations.

Considering that salmon lice levels display regional variations across different geographical locations, different regulations and practises have been developed to counteract the lice problem. In Norway, the lice problem has been prominent for many years. Hence there have been imposed strict regulations that seek to keep the lice prevalence at low- to moderate levels. In 2013, an upper limit was established for the average number of adult female sea lice per fish. If the number exceeds 0.5 female lice per fish, the fish farmer is obligated to slaughter the remaining fish to combat the issue (Norwegian Food Authority, 2016)[5]. In 2017, the Traffic Light System was implemented to

[5]The Norwegian Food Authority can, however, give exceptions to the lice levels under certain circumstances.

regulate the allowed *production levels* at each locality based on lice prevalence in wild salmon populations. This system divides the coast into 13 distinct production areas, numbered from 1 to 13, with 13 being the northernmost zone. Each area is assigned a color code representing the current state of biodiversity. Green zones may increase production every two years, while red zones must reduce it. In yellow zones, production remains unchanged from the previous assessment period. An illustration of the current assessment for 2022-2024 can be found in Appendix A.

Sandvik et al. (2021) identifies a correlation between higher salmon lice prevalence and warmer waters. Hence, salmon lice levels vary across the different salmon farming locations covered in our study. In Chile, which is the world's second-largest salmon producer, there are in general warmer waters compared to Norway. The sea lice levels have led to both high infestation rates, the development of resistance to treatments as well as environmental concerns. Norway and The Faroe Islands are regions that share similarities regarding both the climate and the stringency of their legislation. Through efficient management, coordinated production cycles, and treatment methods such as cleaner fish, they have managed to maintain relatively low salmon lice levels when compared to global levels. In Australia the main portion of their production is located in the colder waters of Tasmania. Here, they face other parasite challenges, with amoebic gill disease (AGD) being more prevalent than salmon lice (English et al., 2019). The observed variations in salmon lice levels are attributed to the particular environmental elements, business practices, and laws that are specific to each region, highlighting the significance of individualized and flexible control methods.

2.3.2 Lice Treatments

The treatments employed to eradicate salmon lice can have side effects that constitute a serious danger to the biodiversity of marine ecosystems (Grefsrud et al., 2022). One negative side effect is the potential harm to non-target species in the surrounding environment. Considering that sea lice is a crustacean species, other species within the same family are susceptible to certain medications that are aimed to kill the parasite. As a result, other crustacean or marine species that are exposed to the therapy and are not the target species can also sustain a loss.

Another threat named in the report is the development of resistance against certain treatment methods. By having less effective treatment methods, while also making the lice species more endurable, the effect might exacerbate the impact of lice on biodiversity (Grefsrud et al., 2022). The use of antibiotics may contribute to the growth of bacteria that are antibiotic-resistant, endangering both environmental and human health. Worldwide, the incidence of antimicrobial resistance (AMR) is spreading due to indiscriminate usage of antibiotics (Sagar et al., 2023). Hence, the industry has been turning to alternative treatment methods without antibiotics. Companies in Norway and the Faroe Islands have historically been using less antibiotics compared to their counterparts in other regions, namely in Chile, where the usage has been more widespread (Norwegian Seafood Council, 2020; Lozano et al., 2018).

Previously, chemical pesticides and other pharmaceutical products were used as the main treatments for salmon lice. However, the use of alternate techniques, like cleaner fish[6], physical removal, and H_2O_2 treatments, have been prompted by concerns about the adverse effects of these treatments on biodiversity and the emergence of resistance.

2.3.3 Escapes

Farmed salmon escapes from aquaculture facilities is a major concern for marine biodiversity. Escaped farmed salmon can have a wide range of negative effects on the surrounding ecosystems and wild fish populations (Grefsrud et al., 2022). One of the main concerns is the potential genetic alteration of wild salmon populations. Interbreeding between wild and farmed salmon can result in the proliferation of adaptive traits with a consequence of loss in the genetic diversity of

[6] A more environmentally friendly option is to use cleaner fish, which are small fish used in the salmon farming industry to manage sea lice populations. Species such as lumpsuckers are introduced into salmon pens to naturally control sea lice populations by feeding on them.

wild populations. This may endanger the species' long-term longevity and reduce their chances to successfully adapt to changes in the ecosystems. As mentioned above, farmed salmon may also carry parasites or diseases that, if they escape, can spread to wild fish populations. The introduction of these pathogens to wild populations can lead to increased mortality, lower fertility, and long-term population decreases, severely harming biodiversity.

2.4 Aim of Dissertation

The primary objective of our study is to investigate the "blind spot" that is the relationship between biodiversity and financial performance in aquaculture. First, we examine a local regulatory framework aimed at protecting biodiversity with the financial performance of companies operating in the salmon farming industry. Next, we determine the significance of key biodiversity impact variables in aquaculture for financial performance at a global level. Hence, we answer the following two research questions in our dissertation:

How do local regulations aimed at protecting biodiversity in the aquaculture industry affect the financial performance of salmon farming companies?

How do the biodiversity impact variables Lice Prevalence, Lice Treatments, and Escapes, affect the financial performance of salmon farming companies?

3 Literature Review

In this chapter, we first examine the role of policy and regulation in promoting sustainable practices and biodiversity. Second, we briefly discuss the broad topic of ESG, exploring key concepts and debates surrounding the impact of ESG factors on financial performance. Third, we delve into the specific area of biodiversity conservation, reviewing current research on the relationship between biodiversity and profitability. Finally, we focus on the aquaculture industry, discussing and reviewing the literature on policies and regulations to promote sustainable practices and minimize the biodiversity impact. Additionally, we review the literature on the relationship between sustainable practices and financial performance.

3.1 Impact of Policy and Regulation on Business Performance

Policies that connect environmental sustainability and economic growth profoundly shape business strategies and impact overall market activity (Costanza et al., 2017). As such, changes in regulations induce considerable impacts on the way firms operate and consequently on their financial performance (Wagner, 2005). Kozluk & Zipperer (2015) suggests that conventional perspectives tend to view environmental policies as a potential hindrance to economic activity, particularly in the short to medium term. This view stems from the perception that such policies not only increase costs without a matching increment in output, but also impose limitations on the range of viable production technologies and outputs. However, Kozluk & Zipperer (2015) highlights that many of these studies are subject to the specific contexts in which they are conducted, arguing that their conclusions may not be universally applicable. Kozluk & Zipperer (2015) contends that DiD studies offer the most effective approach to measure policy effects at a company level. In the context of aquaculture, Tveterås et al. (2012) investigate the efficiency and productivity growth in the global salmon farming industry. The study establish that the industry experienced significant technical efficiency improvements and productivity growth, with variations across countries reflecting different regulatory environments, among other factors. This research underlines the critical role of policy and regulation in shaping the aquaculture industry's performance. Nonetheless, the existing literature falls short of comprehending the financial consequences of policies and regulations specifically designed to protect biodiversity. We examine the financial consequences of biodiversity-centric regulations during the period following Tveterås et al. (2012) study within the context of the salmon aquaculture industry.

Estimating the impact of policy effects is integral to empirical research in finance, accounting, and legal studies. The DiD method has emerged as a central tool for making causal inferences in these disciplines. Between 2000 and 2019, there were 744 papers using the DiD design published in the top five finance or accounting journals (Baker et al., 2022). One of the primary advantages of the DiD method is its capacity to control for unobserved heterogeneity that remains constant over time, effectively reducing bias in policy effect estimates. Martins (2022) explore how competition influences firms' environmental and ESG practices in developing markets. His findings suggest a negative adjustment in ESG practices following a competition shock. In contrast, Flammer (2014) uncovers that increased competition can enhance ESG practices among U.S. firms, supporting the notion of "CSR[7] as a competitive strategy" that enables firms to distinguish themselves from their international competitors. Moreover, Bennear & Olmstead (2008) apply the DiD method to assess the impact of information disclosure requirements on the quality of drinking water in the United States. Their research concludes that such requirements contributed to declining drinking water standard violations. These studies collectively underline the efficacy of the DiD approach in assessing the influence of ESG and environmental policies on corporate performance, providing valuable insights for policymakers and stakeholders. The DiD method, therefore, offers a robust analytical tool for future research at the intersection of regulatory changes, sustainability, and financial performance.

[7]CSR: Corporate Social Responsibility

3.2 Exploring the Complex Relationship between ESG and Financial Performance

ESG considerations are becoming more widely acknowledged for their influence on financial returns. By enhancing environmental, social, and governance performance, companies can improve their long-term success and attract more investors. Literature reviews, such as Stern (2021) (which is a meta-study of more than a thousand papers in the period 2015-2020) and Friede et al. (2015) (who assess over 2200 studies in the period 1970s-2015), indicate a growing recognition of the influence of ESG on financial performance. In the work of Friede et al. (2015), roughly 90% of studies find a non-negative relationship, referencing a substantial body of literature that finds a positive or neutral relationship between ESG and financial gains, suggesting that companies with strong ESG evaluations are better positioned to manage risk, enhance reputation, attract and retain employees and customers, and generate sustainable profits (Stern, 2021; Gillan et al., 2021; Friede et al., 2015; PRI, 2019; Sassen et al., 2016). As pointed out in Stern (2021), important contributors to the strengthening of this trend are the development of regulations and higher public awareness in later years. Studies demonstrate that firms with higher ESG ratings exhibit higher stock returns, lower cost of capital, and more profitable operations (Bassen et al., 2006; Landi & Sciarelli, 2018).

However, from a particular set of papers covered in the literature reviews mentioned earlier, a contrasting line of research finds ESG factors may have negative or no impact on financial performance (Stern, 2021; Friede et al., 2015; Zaiane & Ellouze, 2022; Bhagat, 2022). Investigating 600 firms on STOXX Europe, Zaiane & Ellouze (2022) uncover that in environmentally non-sensitive[8] industries, large firms have a tendency to engage in symbolic CSR practices. Stern (2021) find that ESG disclosure on its own does not drive financial performance. According to Bhagat (2022), funds investing in companies that publicly embrace ESG sacrifice financial returns without gaining much in terms of actually furthering ESG interests. These results underline the complex and context-dependent relationship between ESG and financial performance (Bhagat, 2022; Adler & Kritzman, 2008; Kanuri, 2020; Velte, 2017). The evidence that the ESG topic is an increasing trend is illustrated by the number of Google searches, as indicated by Google Trends in Figure 3.1.

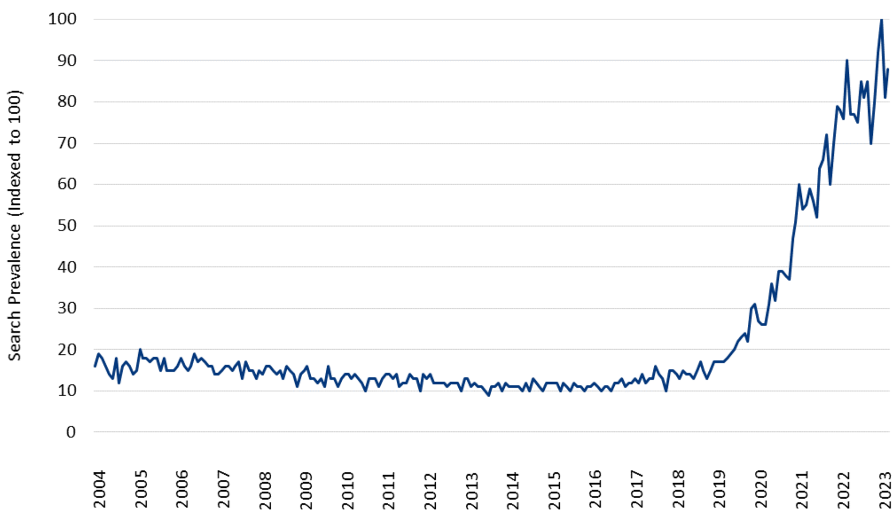

Figure 3.1: Google Trends: Searches for ESG (2004-2023). The numbers on the y-axis denote search popularity relative to the chart's maximum point. E.g., a ranking of 100 signifies the highest popularity of ESG, while a ranking of 50 means ESG is only half as popular. Adapted from: Google Trends (2023).

[8]Firms characterized as sensitive typically operate within sectors including oil and gas, chemical manufacturing, tobacco, mining, transportation equipment production, paper and pulp sector, as well as the steel and metal industries (Zaiane & Ellouze, 2022).

Investigating the nexus between ESG-factors and financial performance, researchers use various measures of profitability (Stern, 2021). The most commonly used measures of firm performance include accounting measures (Hamdi et al., 2022; Zaiane & Ellouze, 2022; Stern, 2021; Friede et al., 2015; Ullah et al., 2018; Velte, 2017), market measures such as Tobin's Q (Zaiane & Ellouze, 2022; Stern, 2021; Nygård, 2020; Velte, 2017), and risk measures such as volatility and beta (Stern, 2021). The choice of metrics often depends on the research question and theoretical framework. For instance, accounting measures reflect a firm's operational profitability and efficiency, whereas market measures capture the market's outlook on the company's future prospects and growth potential. Risk measures capture a firm's exposure to external shocks. The accounting approach is typically measured with return on assets (ROA), given in Equations 3.1, or return on equity (ROE). Each measure has its own limitations and potential biases. For instance, market measures may be affected by market sentiment and volatility and are limited to public companies. Moreover, accounting measures (ROA and ROE) can be skewed by different choices regarding their capital structure (Velte, 2017). However, while more debt increases total assets, the effect on ROA hinges on how efficiently the additional assets contribute to generating profits.

$$\text{ROA} = \frac{\text{Net Income of Firm}}{\text{Total Asset Value of Firm}} \tag{3.1}$$

In analyzing the intricate interplay between ESG and financial performance, several studies resort to Pooled Ordinary Least Squares (POLS) (Garcia et al., 2017; Nirino et al., 2021; Lins et al., 2017). However, the intrinsic heterogeneity often present within panel data renders POLS less than ideal, with potential results skewed towards bias and inconsistency due to the violation of the zero conditional mean error assumption. Fixed and Random Effects models offer a solution to this particular challenge by allowing for heterogeneity. Despite this, Fixed and Random Effects models exhibit limitations of their own, mainly their lack of provision for potential endogeneity dilemmas resulting from omitted variable bias and reverse causality. Studies indicate that a significant majority, around 90%, of articles found in top-tier journals may fail to effectively tackle the issue of endogeneity bias (Ullah et al., 2018). Ketokivi & McIntosh (2017) state that the existence of endogeneity bias can lead to inaccuracies in the determination of coefficient sign. GMM adequately address endogeneity and permits the incorporation of lagged variables, thereby permitting the dependent variable to be influenced by past performance (Wooldridge, 2010). Moreover, Fixed and Random Effects strongly rely on the fact that the data generating process is static. Yet, in line with Chen & Xie (2022) and Wintoki et al. (2012), who investigate ESG and profitability, the nature of financial performance and ROA is dynamic (Hamdi et al., 2022; Ullah et al., 2018). Hence, in our pursuit of robustness and accuracy in our findings, we utilize the GMM.

3.3 Underestimating the Risk of Biodiversity: Implications for Business and Finance

Biodiversity is emerging as a critical focus in the global sustainability agenda. Over the past decades, significantly more biodiversity has been destroyed than conserved due to economic activity (Dasgupta, 2021; WWF, 2022). Recognizing the inextricable link between biodiversity and economic development, the Aichi Targets (updated in 2022) are established as a set of global goals to mitigate biodiversity loss, to safeguard natural resources and promote sustainable growth (CBD, 2020). Achieving these targets is paramount not only for biodiversity preservation but also for sustaining long-term financial performance. For instance, as described in the Chapter 2, concerns have arisen around the salmon farming industry in Tasmania, where excessive levels of dissolved nitrogen and nutrients from fish farms have led to an alarming proliferation of green algae. This scenario exemplifies the rising risks that companies face from operational disruptions and reputational damage tied to environmental degradation (CBD, 2020). Nevertheless, asset managers (ShareAction, 2023) and non-financial companies are incentivized to ignore biodiversity risks (Nedopil, 2022). The results indicate that fundamental financial decision-making theory on costs, revenues, and risks is not adequately integrated with biodiversity finance (Nedopil, 2022). Moreover, the understanding of how business activities impact biodiversity and the financial risks associated with biodiversity loss is currently incomplete (Nedopil, 2022).

The political, economic, and financial systems fail to adequately consider nature's contributions, as evidenced by the undervaluation of services such as carbon capture by forests (Deutz et al., 2020). Over half of the world's total GDP, equivalent to $44 trillion, is either moderately or heavily reliant on nature and its services (WEF, 2020). Consequently, this significant economic dependency reveals a considerable exposure to risks stemming from the potential loss of these natural resources (Costanza et al., 2017). To reverse biodiversity loss, it is estimated that investments up to USD 967 billion annually over the next ten years are needed (Deutz et al., 2020). This contrasts with the materialised yearly biodiversity finance investments of USD 100 billion (OECD, 2018).

Furthermore, a significant challenge for risk evaluation is the lack of a "common language" concerning biodiversity and its financial risk (Nedopil, 2022). Biodiversity impact indicators have become increasingly important for investors, financial institutions, and company managers (Biodiversity Indicators Partnership, 2011; Addison et al., 2018). As defined by the Biodiversity Indicators Partnership (2011), an indicator is a measure or metric based on verifiable data that conveys information about more than itself. While many researchers have developed biodiversity indicators, IUCN has identified a lack of indicators to measure biodiversity impacts at the corporate level (Addison et al., 2018). Developing such indicators can help assess corporate biodiversity performance more effectively. To face this issue, several initiatives are underway to define how companies and institutions can assess and measure their impacts, set targets, and disclose information. These initiatives include e.g. the Taskforce on Nature-related Financial Disclosures, the Science-Based Target Network, and the Partnership for Biodiversity Accounting Financials (TNFD, 2023; SBTN, 2023; PBAF, 2022; IFRS, 2023; EFRAG, 2023; GRI, 2023).

Despite progress in developing biodiversity impact indicators, key sources of uncertainty remain in the existing measuring tools. Santini et al. (2017) states that even though a large number of metrics are available, they are not necessarily coherent with each other. Even if project/firm-level metrics would be available, the lack of data to measure biodiversity impacts and dependencies continues to be challenging (Skidmore et al., 2021). Moreover, the update frequency of data and model granularity are among the main sources of uncertainty (Hilton & Lee, 2021). Some parts of the tools may use outdated datasets, while others may have issues capturing significant changes that take place at a smaller scale. Consequently, finance and accounting scholars have been unable to find a broadly applicable solution (Addison et al., 2018). Tackling these challenges will be crucial to ensure that biodiversity impact indicators are reliable and informative for decision-making. We contribute to the current development of biodiversity indicators by creating a novel dataset of publicly available metrics to assess the impact of aquaculture, specifically on biodiversity.

Research on biodiversity and financial performance focuses on various aspects of this complex relationship. The private sector's involvement in environmental problem-solving has been a particular area of interest. For decades, climate conferences shunned the idea of private sector involvement. However, during COP15 it became clear that this stance was receding into the past (Lombrana et al., 2022). Rubino (2000) emphasizes why conservation of biodiversity needs private funding, but state that "before committing larger amounts of money, these potential investors need case-studies, examples, and other proof that money can be made in biodiversity-linked markets". Parker & Cranford (2010) introduces a framework based on modules to help key stakeholders compare options for financing biodiversity and ecosystems. Sumaila et al. (2017) investigates the investments required for meeting conservation targets, concluding that improving knowledge generation regarding the insurance value of biodiversity is vital. Despite the importance of private sector involvement, the financial services industry has largely ignored the planet's rich biodiversity (Lombrana et al., 2022). In fact, corporations and those funding them have contributed to the destruction of the world's natural resources, with animal populations dropping by an estimated 69% since 1970 (WWF, 2022). The potential to transform the regulatory landscape for the investment industry exists in the agreement made at COP15 in Montreal to protect one-third of the Earth's land and water by the end of this decade (Lombrana et al., 2022). Currently, a mere 17% of the world's land and 10% its marine areas are protected, with the quality of such safeguarding varying significantly. Inherently, leaving ample room for improvement (WWF, 2022).

The literature on biodiversity and financial performance specifically is novel and needs further investigation. In this paper, we contribute to this effort by collecting and combining data on recognized issues within the aquaculture industry to assess companies objectively and by connecting their performance within biodiversity to financial performance. Through this approach, we investigate the role that investors and regulators play in promoting biodiversity conservation and building a more sustainable future.

3.4 Sustainable Practices and Financial Performance in Salmon Farming

The rapid growth of aquaculture as the world's fastest-growing animal-based food sector has been attributed to the combined effects of productivity and demand growth (Smith et al., 2010). The emergence of new markets and product development has driven demand growth, making it an increasingly crucial factor in the industry (Asche et al., 2011; Brækkan & Thyholdt, 2014). Moreover, productivity growth has substantially reduced unit costs, allowing fish farmers to generate higher output with the same amount of input and benefit from more cost-effective production processes (Asche, 2008). Sikveland et al. (2022) examines the profitability differences between publicly listed and privately held firms in Norwegian salmon aquaculture, and find no statistically significant disparities in ROA, despite private firms having a higher ROA on average.

The salmon farming industry faces comprehensive policies and regulatory measures to ensure sustainable practices and mitigate adverse impacts. Stakeholders in the Norwegian aquaculture industry generally support sustainable aquaculture but lack a clear definition of the term (Lindland et al., 2019). According to whole river experiments in Ireland and Norway, escaped farmed salmon can significantly alter wild salmon populations, emphasizing the need for further measures to reduce escapes and prevent interbreeding (Hindar et al., 2006). Greaker et al. (2020) investigate environmental policy and innovation in salmon farming and find that innovations with a high public good content, such as closed-cage production[9] is not adequately adopted by private firms unless they are backed by targeted government intervention. Greaker et al. (2020) states that there is a need for policymakers to stimulate sustainable innovation.

Addressing the specific challenges of sustainability and financial performance in salmon farming industries necessitates tailored research and policies. In Chile, research has concentrated on tackling issues such as the overuse of antibiotics, disease outbreaks, and environmental degradation. In 2021, 463.4 tons of antibiotics were used in Chile (compared to Norway that had none[10]), allowing the development of antibiotic-resistant bacteria in sediments (Molinari, 2022b; Quiñones et al., 2019; Lozano et al., 2018). Although studies have examined the economic implications of adopting more sustainable practices like reducing antibiotic usage and employing non-chemical treatments for sea lice control, implications require further research (Lozano et al., 2018; Buschmann et al., 2009; Zalcman et al., 2021). In 2003, as described in the Chapter 2, the Faroe Islands implemented one of the most comprehensive and stringent aquaculture veterinarian regulations, eliminating the use of antibiotics (Stockholm Resilience Centre, 2019; FaroeIslands, 2019). However, since the introduction of mechanical and thermal lice treatments in 2005, fish mortality has gradually increased (ICES, 2022). Nevertheless, it should be noted that profitability has been consistently high and positive (ICES, 2022). Moreover, trade regulations in the US stipulate that nations must prove their fishery and aquaculture practices to be as efficacious as the US Marine Mammal Protection Act. Failing to do so could potentially result in a revocation of their license to export seafood products to the US market, as indicated in the study by (Williams et al., 2016). Ultimately, understanding the specific challenges, regulations, and environmental contexts in each country is essential for developing effective strategies to promote sustainable salmon farming practices and optimize financial outcomes.

There is growing interest in the interdependencies between aquaculture and sustainability. However, there is a gap in the literature when it comes to connecting biodiversity and financial performance within the aquaculture sector. The research of Nygård (2020) on the Oslo Seafood Index offers valuable insights, revealing that higher quality sustainability reporting initiatives, such as

[9] In closed-cage production intake water is pumped from deeper water layers. These will severely limit the number of escapes as well as sea lice infection (Nilsen et al., 2017).

[10] Antibiotics data provided by the Norwegian Veterinary Insitute.

GRI[11] standards, GSI[12], and ASC[13], positively impact market value by reducing information asymmetry between managers and equity holders. Moreover, the study uncover that reporting without any standard had no significant effect on market value. A broader examination of the literature uncovers additional, yet sparse, research on financial performance in aquaculture. For example, Macfadyen et al. (2012) conduct a value-chain analysis of the Egyptian aquaculture sector, concluding that the industry significantly contributes to employment and societal value-added. The study identifies input-related factors as crucial determinants of performance. Similarly, Lipton & Kim (2007) assess the economic viability of offshore aquaculture in Korea, finding that financial performance becomes considerably riskier when survival rates decrease. While these studies provide some valuable insights, the overall scarcity of research focusing on the relationship between profitability and aquaculture highlights the need for further exploration in this area. A deeper understanding of the complex interplay between biodiversity and financial success can help guide industry practices, inform policy decisions, and drive responsible investments in the sector. In conclusion, the current literature exhibits a research gap in connecting sustainability within aquaculture and financial performance, underscoring the need for additional investigation in this domain.

Within the literature on aquaculture, methods used to assess relationships with financial performance often employ fixed effects model. Studies such as Nygård (2020); Sikveland et al. (2022); Asche et al. (2018) rely on fixed-effects to examine various aspects of aquaculture, including environmental CSR trends, profitability differences between public and private firms, and the impact of firm size and price variability on profitability. Wintoki et al. (2012) highlights that fixed-effects may be biased in cases where dynamic relationships exist between current values of explanatory variables and past realizations of dependent variables. To our knowledge, previous research has not considered the potential bias arising from dynamic relationships in the context of aquaculture. In response to this gap, our study contributes to the aquaculture literature by incorporating a dynamic approach to the analysis, offering a novel perspective on the relationship between biodiversity and financial performance.

Our research is significant due to its potential to provide valuable insights for stakeholders such as industry participants, regulators, and investors. One key benefit of this research is the ability to guide sustainable practices within the industry. By understanding the relationship between biodiversity and financial performance, companies can identify and adopt best practices that promote responsible and sustainable aquaculture, optimize their operations, and minimize negative environmental impacts. Furthermore, research can inform the development and implementation of effective regulations, guidelines, and incentives by regulators and policymakers. By analyzing the factors contributing to better profitability while preserving biodiversity, governments can tailor their policies to encourage responsible growth and sustainable practices in the sector. As investors increasingly prioritize ESG factors in their decision-making, research demonstrating a positive relationship between biodiversity conservation, ESG performance, and financial success can attract more investment in sustainable aquaculture companies. This, in turn, can drive growth and innovation in the sector, fostering a more environmentally responsible industry.

[11] GRI: Global Reporting Initiative
[12] GSI: Global Salmon Initiative
[13] ASC: Aquaculture Stewardship Council

4 Data and Variables

In this study, we compile, process and synthesize data from various sources to construct two novel panel datasets, one consisting of 40 salmon farming companies for the 2014-2021 period and the other consisting of 41 companies and an additional biodiversity variable between 2016-2021. These enable us to conduct a comprehensive analysis of the relationship between biodiversity impact variables and a company's financial performance. Our empirical work utilizes a balanced panel of salmon farming companies from Chile, Norway, the Faroe Islands, Australia, and New Zealand. All companies are given in Appendix B. This study includes 36 of the largest Norwegian salmon farming companies in terms of slaughter weight in 2021. In addition to the Norwegian companies, we also collect data on 5 additional companies listed in the GSI database. As mentioned in the Chapter 2, these countries account for over 80% of the global salmon production. In this chapter, we begin by describing our dependent variable, ROA, which serves as a proxy for financial performance. Subsequently, we explain the control and explanatory variables utilized in our analysis. We also provide an in-depth account of the data cleaning process, specifically focusing on the impact variables and discussion on the data quality. Finally, we present the summary statistics, offering a thorough understanding of the factors and their distribution in our study.

4.1 Variable Selection

We draw upon existing literature investigating the nexus between ESG factors and financial performance to select the variables for inclusion in our model. We examine research on this domain and identify key factors that are relevant to our study and may contribute to a deeper understanding of the linkage on biodiversity impact variables and financial returns.

4.1.1 Independent Variable

In our model, we utilize ROA as a proxy for financial performance. This measure is extensively employed in studies investigating the relationship between ESG factors and financial performance (Stern, 2021; Kyere & Ausloos, 2021; Friede et al., 2015; Velte, 2017; Fischer & Sawczyn, 2013; Guest, 2009). Regarding the data collection process, we obtain firm-level data on ROA for Norwegian companies for the years 2014-2021 from the Brønnøysund Register Center[14] Moreover, we gather financial data for non-Norwegian companies from EIKON. Our research contributes to the existing literature, specifically to the work of Nygård (2020), who uses a market-based measure (Tobin's Q) as the dependent variable when examining the interplay between sustainability initiatives and financial returns in the Norwegian aquaculture sector. In contrast, we employ an accounting-based measure (ROA) and expand the scope of our analysis to include a larger set of both Norwegian and international companies, thereby enhancing the scope of our contribution to the literature.

4.1.2 Dependent Variables

We employ several explanatory variables identified in the risk assessment in the Chapter 2 that are relevant to biodiversity and environmental management in salmon farming. The first factor, the number of sea lice, is a critical factor in assessing the environmental impact of salmon farming operations. This aspect has implications for financial performance, as a high prevalence of sea lice may lead to increased operational costs and potential reputational risks for the company. The second dimension we consider is the amount of medicine used in lice treatments (including antibiotics), administered through either feed or bath therapies. The use of medicine can influence financials through factors such as increased costs depending on the mitigation effort and potential regulatory consequences. Next, we include the usage of H_2O_2 as an explanatory variable, a treatment method that does not rely on antibiotics or chemicals. H_2O_2 usage can impact financials

[14] Brønnøysund Register Center is the Norwegian government agency responsible for maintaining the country's official registers of legal entities, such as businesses and organizations (Brønnøysundregistrene, 2022).

through its effects on fish welfare and increased mortality with inappropriate application. Finally, we incorporate the number of escaped fish as a regressor. Escapes can affect a firm's profitability due to the loss of stock, on top of the application of fines for damaging the natural environment and potentially suffering from reputational damage. By including the aforementioned explanatory variables in our model, we provide a thorough examination of the relationship between biodiversity management practices within the aquaculture industry and the financial performance of the enterprises involved.

4.1.3 Control Variables

In determining the appropriate control variables for our analysis, we incorporate factors commonly employed in literature that has an impact on financial performance. Based on the meta-analysis by Orlitzky et al. (2003), the most frequently used control variables include firm size, systematic and unsystematic risk, and industry dummy variables. Given that our study focuses on public and private salmon farming companies, we exclude systematic risk and the industry dummy variable. In accordance with the literature, we use the total debt-to-total assets ratio. In our model, it is identified as *Debt* as a proxy for unsystematic risk for all companies (Velte, 2017). Previous studies suggest that firms with high Corporate Social Performance (CSP) ratings are perceived as less risky due to their "insurance-like" effects, which consequently result in a lower cost of debt capital (Orlitzky et al., 2003). To account for the size of each company, we employ two measures. Firstly, we utilize firm size (*Size*), measured by the natural logarithm of total assets. As Fischer & Sawczyn (2013) notes, the relationship between firm size, CSP, and financial performance is associated with stakeholders' expectations and concerns regarding socially responsible activities. Additionally, larger firms often benefit from economies of scale or scope (Velte, 2017). Secondly, we include the number of employees (*Nb. Employees*) as an alternative measure of company size. Moreover, enterprise age is a standard control variable. Boone et al. (2007) argue that complexity increases with firm age, but this correlation becomes ambiguous once a firm reaches maturity. Given that our sample contains companies from different databases and mergers have occurred at varying dates, the inclusion of business age does not provide a clear insight into our context. Data on the control variables are gathered from the Brønnøysund Register Center, EIKON, and companies' websites, ensuring a comprehensive and reliable foundation for our analysis.

4.2 Data Cleaning

For the Norwegian companies, we begin by examining publicly available datasets provided by The Directorate of Fisheries, which comprises 153 companies with commercial licenses for salmon and trout production in Norway. We subsequently eliminate 41 of these firms due to ownership by other companies, but incorporate their impact variables into the respective controlling entities. Notably, approximately 100 companies account for the total supply of salmon in Norway, with 23 of the largest companies producing nearly 80% of the country's annual volume (MOWI ASA, 2021).

We further remove entities with missing information for the period under consideration and ensure that each company appeared only once in our sample. In cases where a company operated in multiple countries, such as Grieg does in Norway and Canada, we included only the data pertaining to the specific country of interest in our analysis, utilizing the financial data for the company from the relevant country. When a company appears in both the Norwegian selection and the GSI database, we prioritize and utilize data from the GSI source.

4.2.1 Location Structure

When dissecting the impact variables in our study, there is a distinction between data from Norwegian companies and those in the Global Salmon Initiative (GSI) database. While GSI data is company and country-specific, Norwegian company data not included in GSI is location-based, which makes company aggregation more difficult. Thus requiring further processing.

Norway's coastline is divided into 13 production areas, each comprising several locality permits that authorize aquaculture operations. Consequently, a detailed mapping of localities and the identification of companies involved in joint ventures (JVs) is required. Every company engaged in salmon farming within Norway has recorded its locality permits in the Norwegian Aquaculture Registry (Fiskeridirektoratet, 2022). We gather data as of January 1st for each year, from 2014 to 2021. Although localities may be traded throughout the year, the number of localities per company remains relatively stable each year. As such, the impact of deviations in the locality structure during the year is negligible. The Directorate of Fisheries uses monthly biomass reports from localities to track which company is currently operating at each location. However, this information is deemed financially sensitive and is not publicly accessible. It's possible for a single locality to be operated by the owner or be under a joint venture involving multiple companies, leading to a non-linear relationship between the owner and operator of a locality. JVs enable companies to fully utilize a locality in case of a mismatch between a company's permitted biomass and the locality's maximum permitted biomass (Hosteland, 2018). The Aquaculture Registry does not indicate explicit details regarding the main salmon farming firm at a shared locality. To determine the primary operator, we examine the permits for each locality. However, the Registry does not specify the proportion of production permits used by enterprises at a given location. To overcome this challenge, we distribute production permits based on the share of a permit. We assume that if a firm possesses more than 80% of a locality's production permits, it's deemed the chief operator with an assigned weight of 1. A company with less than 20% of the permits is assigned a zero weight, while those controlling between 20% and 80% of the permits are given a weight of 0.5. Table 4.1 summarizes the weighting of JVs. Our assessment of a company's impact on biodiversity relies on the established weightings for each locality. For instance, if multiple companies are involved in a JV at a locality, lice abundance at that location is considered half of the total abundance for each company. While this approach may not precisely match the information provided in companies' external reports, it treats all companies fairly and equally, offering sufficient detail on locality structure for biodiversity measuring purposes.

Table 4.1: Share of Production Permits and Corresponding Weights

Share of permit from joint venture	Weight
$\geq$ 80%	1
20%-80%	0.5
$\leq$ 20%	0

The table above illustrates the weighting scheme for Norwegian companies for assigning ownership based on the share of production permits held by a company in a locality. If a company holds over 80% of the permits in a locality, it is considered the primary operator, and its weight is set to 1. Companies with a share of permits between 20% and 80% receive a weight of 0.5, whereas those holding less than 20% of the locality's permits have a weight of zero. This weighting system allows for a fair and consistent method of determining the primary operator in localities involving multiple companies.

4.2.2 Lice Prevalence

As discussed in Chapter 2, sea lice are a naturally occurring parasite, infesting numerous fish species and having a detrimental effect on fish health, welfare, and farm productivity, thus influencing the biodiversity within aquaculture facilities. We collect and use data from both GSI member companies and Norwegian companies not affiliated with GSI. For GSI members, sea lice prevalence is reported as the average number of adult female lice per fish per month, which we aggregate on a yearly basis. For non-GSI Norwegian companies, we utilize weekly lice data reported to the Norwegian Food Safety Authority and BarentsWatch, resulting in a dataset of 224,812 observations from 2014 to 2021. To clean the data for Norwegian companies, we first remove reports from locations not associated with the 36 companies within our scope. Next, we determine the lice prevalence for each location and company, aggregating these numbers for all localities connected to a given firm within a year. We further divide this aggregated figure by the number of counts conducted by the company during that year. In cases involving joint ventures, the lice prevalence is divided by two. The final dataset comprises the average number of mature female sea lice per year.

4.2.3 Lice Treatment

In the context of sea lice management, it is crucial to monitor the usage of licensed medicines when lice levels approach the advised limits. The amount applied is quantified by the active pharmaceutical ingredients (API) used (in grams) per tonne of Live Weight Equivalents (LWE). We compile data on lice treatments employed in feed and bath. For lice management in bath we make another segregation between medicine usage including antibiotics and chemicals, and H_2O_2. By segregating we get a more comprehensive understanding of the sea lice management practices in the salmon farming industry.

For companies in the GSI database, we collect data on a per-company basis directly. In the case of Norwegian companies, we rely on locality specific data from BarentsWatch. These numbers are reported weekly to the Norwegian Food Safety Authority, specifying whether entire pens or only portions of localities have undergone therapies. Due to uncertainties surrounding the extent of lice management procedures within a locality, we treat each data point as one event. Our lice treatment dataset encompasses 38,570 observations from 2014 to 2022. From this information, we aggregate the number of in-feed-, H_2O_2-, and other in-bath treatments. Subsequently, we categorize them according to the specific type of medicine employed. Next, we obtain data on the total grams of API used per type of medicine in both bath and feed treatments throughout Norway, dividing this figure by the total number of therapies to derive the average grams of API per treatment. We then multiply the average grams of API by the number of mitigation efforts for each medicinal type per company, taking into account the various active ingredients. Finally, we sum the total amount of g API utilized in treatments and divide this by the total LWE per company. LWE is calculated from slaughter weight obtained by Kontali[15] and multiplied by a factor of 1.25 (SSB, 2017; FAO, 2023). For Norwegian companies, this results in the quantity of API used (in grams) per tonne of LWE, a measure consistent with the GSI reporting.

4.2.4 Escapes

The final biodiversity impact variable we examine in this study is the number of escaped salmon. To evaluate escapes, two approaches can be considered: examining escape incidents or quantifying the number of escaped fish. A single escape incident may involve anywhere from one to thousands of escapees, resulting in varying degrees of impact on the environment and firm rating. It is important to note that escaped farmed salmon can have a long-lasting effect on biodiversity, as they can survive in the wild for several years. Consequently, we employ a three-year rolling average of number of escaped salmon, aligning with MSCI's timeframe for ranking controversies, where an escape incident is considered "a single event such as a spill, accident, regulatory action..." (MSCI, 2023).

For GSI member companies, escape data is readily available on an annual basis. For non-GSI members, we obtain data on escapes from 2014 to 2022 from The Directorate of Fisheries, using the number of escaped salmon as our indicator. We first create a subset containing observations for the relevant companies, resulting in 300 escape incidents. Subsequently, we aggregate the number of escapees for each company per year, dividing the total number of escaped salmon by the number of localities per company. Finally, for all companies within our scope, we transform the escapes counted from an annual basis to a rolling average over three years, yielding the number of escapes per locality on a three-year rolling average basis.

4.2.5 Normalization of Impact Variables

The final step in the data cleaning process involves normalizing all biodiversity variables we utilize in our study through min-max normalization, scaling values between 0 and 10. By doing so we ensure that the data are on a similar scale, which enhances the convergence and stability of our econometric models, in addition to handling problems such as outliers and enhancing the

[15] An overview of slaughter weight for all Norwegian fish farmers with more than six permits was provided to us by Kontali Analyse on February 02, 2023.

interpretability of our results. The lowest-performing companies each year receive a score of 0, while the best-performing company is awarded a score of 10. For all variables except escapes, annual scores are calculated. In contrast, escapes are assessed on a three-year rolling average basis. When normalizing escapes on a 0-10 scale, the highest three-year rolling average figure globally is assigned a score of 0, while salmon farming companies with zero escapes receive a score of 10 for the given year. By rating each company's performance for every year, we generate metrics that enable objective comparison of the companies included in our study. Although min-max normalization is generally robust to outliers, it can potentially amplify their impact if they are not adequately addressed.

4.3 Data Quality

In this chapter, we make an assessment of the quality of the data that is being utilized in our thesis. Given both the novelty of our research area and the dataset, it is crucial to ensure that the data we are using are accurate before making any statistical inferences. Without trustworthy data, any conclusions drawn from statistical analyses can be inaccurate or even misleading. Given that we are utilizing data from multiple providers, it is essential to explain the input sources for our model, as well as the methodological variations and uncertainties associated with each source.

One of the key sources of data we rely on is from the Directorate of Fisheries, a governmental institution that provides valuable information on escaped fish in Norway (*Escapes*). Additionally, we gather data on *Lice Prevalence* and *Lice Treatments* from BarentsWatch, a portal that provides an overview of activity and knowledge in coastal and sea areas in Norway. Here, the data is based on cooperation between 27 Norwegian state agencies and research institutes (Norwegian Coastal Administration, 2021).

In order to gather data on non-Norwegian salmon farming companies, we utilize data provided by GSI. The GSI is an initiative established by global farmed salmon producers committed to improving on industry-wide sustainability and transparency challenges. The members included in GSI represent approximately 40% of the global farmed salmon industry (Global Salmon Initiative, 2022c). Considering that we have collected data from different providers, it is important to assess these individually.

4.3.1 Lice Prevalence

The reliability of the lice data in our study is assessed as *medium*, utilizing reliable sources such as the GSI with strict regulatory measures ensuring accuracy. In Chile, the National Fisheries and Aquaculture Service (SERNAPESCA) is the primary regulatory body responsible for overseeing the aquaculture industry, including salmon farming. In the Faroe Islands, salmon farming is regulated by the Faroese Food and Veterinary Authority (FFVA) and the Faroese Environment. In both countries, the authorities set strict regulations on monitoring, reporting, and managing sea lice. Farmers are required to regularly count sea lice on their fish and report their findings to the authorities. The Norwegian government also place strict regulations on salmon lice policies, having upper limits for average lice levels in the fish pens. The Norwegian Veterinary Institute is responsible for conducting quality controls of lice levels in Norway, and conducting surprise visits in order to oversee that the reports being made are correct. In all countries, if fish farmers are caught falsifying data, they can expect severe penalties.

Although some data reporting still occurs manually, based on a fisherman's knowledge or intuition, digital lice prevalence monitoring has become increasingly more prevalent in recent years. However, there are operational incentives to report lower lice numbers. Moreover, the risk of imprisonment and substantial fines serve as deterrents against falsification. Consequently, we have evaluated the overall quality of the lice data as medium.

4.3.2 Lice Treatments

The overall quality of the lice treatment data is considered to be *high*. Salmon farming companies are subject to strict regulations regarding sea lice control reporting, which is overseen by authorities to ensure compliance and effectiveness. In the Faroe Islands, firms must report the type and effectiveness of treatments used, such as chemical, biological, or physical methods, to the FFVA. Chemical treatments are tightly regulated, and prior approval is necessary before their application (FaroeIslands, 2019). Similarly, in Chile, SERNAPESCA monitors sea lice treatment activities. Companies must report treatment methods, frequency, and effectiveness in controlling sea lice infestations as part of their regulatory compliance (Chilean Government, 2022).

In Norway, sea lice management is regulated by the "Regulations on the control of salmon lice in aquaculture facilities" (Ministry of Fisheries and Coastal Affairs, 2012). Companies must document each lice treatment, including the API used, sea temperature, sensitivity analysis outcomes, and any potential resistance discovered. The Norwegian Food Safety Authority oversees the tracking and monitoring of these reports. Nonetheless, there are a few challenges considering the attribution of medicinal usage aggregated to each company. An example is how the data on Norwegian companies is differentiated on locality level, not for each enterprise, as in the GSI database. Given the aquaculture registry of localities, we can still aggregate the number of treatments for each of the companies respectively. Combining the number of treatments with our data gathered from the Norwegian Veterinary Institute, we are able to give estimates for each of the different lice treatments used at each location. Despite these minor obstacles in data cleaning, the overall quality of lice treatment data is considered to be high.

4.3.3 Escapes

The quality of escape data is considered to be *medium*. Companies are required to report escape incidents as soon as they are detected, providing information on the number of escaped fish, the cause of the escape, and any corrective measures taken to prevent future occurrences. The Directorate of Fisheries in Norway requires reporting of any escapes from aquaculture operations, as stipulated by the Aquaculture Operations Regulations, which aim to minimize the impact of escaped fish on the local environment (Ministry of Fisheries and Coastal Affairs, 2018). However, according to Hytterød (2021), there are no reliable methods of accurately estimating the number of escaped fish during an incident. This makes it difficult to verify whether the number of reported escapes is accurate or not. Considering that fish farmers may have the incentive to under-report escapes due to the possibility of fines and damage to their reputation, this may impact the reliability of the data that has been collected. While new technologies such as AI and camera systems show promise in improving the accuracy of estimates, until a reliable data-driven solution is developed, the quality of escape data is considered as medium.

4.4 Summary Statistics

We construct a novel dataset spanning from 2014 to 2021; however, data for escapes and a company is only available from 2016 onwards. Consequently, we operate with two datasets. To investigate the impact of biodiversity policy and regulation on financial performance, we utilize the dataset covering the period from 2014 to 2021, as the regulation was introduced in 2017. This allows us to examine both pre- and post-regulation periods. On the other hand, when exploring the nexus between biodiversity factors and financial development, we employ the dataset with data between 2016 and 2021 in order to incorporate the number of escaped salmon as a factor in our analysis and include an additional company in our dataset.

The summary statistics for the System GMM model are presented in Table 4.3 for the dataset between 2016 and 2021, including all biodiversity variables. The summary statistics for the DiD model are given in the appendix (Table C.1). The statistics provide an in-depth overview of the key characteristics and attributes of the salmon farming companies included in our study, highlighting the metrics: size, debt, employee distribution, and biodiversity factors. In our sample of salmon farming companies, we observe a certain degree of homogeneity among them. As shown in Table 4.3, there is limited in-sample variability in terms of company size, as proxied by the natural logarithm of total assets. In contrast, debt, represented by the total debt to total assets ratio, exhibits a higher standard deviation due to differences in financing structures across companies, with debt ratios ranging from 0% to 90%. The number of employees displays higher variability, primarily attributable to the three largest companies in our sample: AquaChile (5,200 employees), Lerøy Seafood (5,475 employees), and Mowi (13,984 employees). Combined, these companies account for over 60% of the total number of employees in our 2021 sample.

From Table 4.3, we observe that for the financial performance measure, ROA, the sample firms show a mean profitability of 14.34 percent. The standard deviation of ROA is 11.83, indicating some variability in profitability among the companies. Regarding the biodiversity variables, all factors exhibit scores ranging between the lowest value of 0.00 and the highest value of 10.00. These summary statistics offer a foundation for further analysis and testing, enabling a more in-depth exploration of the interdependencies between a firm's profitability, company attributes, and biodiversity management practices within the salmon farming industry.

Table 4.2: List of variables, description and source

Type	Variable	Description	Source
Dependent variable	ROA	Net income divided by total assets	Brreg, Bloomberg and EIKON
Control variables	Size	Natural logarithm of the total assets	Brreg, Bloomberg and EIKON
	Debt	The ratio of total debt to total asset	Brreg, Bloomberg and EIKON
	Nb. Employees	Number of man-years	Brreg and EIKON
Explanatory variables	Escapes	Escapes score	The Directorate of Fisheries and GSI
	Sea lice Prevalence	Lice Prevalence score	BarentsWatch and GSI
	H_2O_2	Hydrogen Peroxide score	The Directorate of Fisheries and GSI
	Lice treatments feed	Lice treatment feed score	BarentsWatch and GSI
	Lice Treatments bath	Lice treatments bath score	BarentsWatch and GSI

This table outlines each variable's role, description, and data source. The table is organized into four columns. The first column classifies each factor as either dependent, control, or explanatory, which helps delineate their respective functions within the model. The second column provides the name of each variable, including the dependent variable, ROA, as well as the control and explanatory variables under investigation. The third column offers a detailed description of each variable. Finally, the fourth column lists the source or sources from which the data for each factor has been collected, ensuring transparency in our research methodology and data collection process. Brreg = Brønnøysund Register Center, GSI = Global Salmon Initiative.

Table 4.3: Descriptive statistics (2016-2021)

Variable	Obs	Mean	Std. Dev	Min	Max
ROA	258	14.34	11.83	-16.22	58.39
Lice Prevalence	258	9.39	1.09	0.00	10.00
Lice Treatments Bath	258	9.47	1.32	0.00	10.00
Lice Treatments Feed	258	9.36	1.52	0.00	10.00
H_20_2	258	9.25	1.43	0.00	10.00
Escapes	258	9.91	0.73	0.00	10.00
Direct Labour	258	814.09	2275.81	5.50	14866.00
Size	258	12.19	1.22	10.20	15.75
Debt	258	44.03	19.41	0.01	89.88

This table presents the summary statistics for our dataset, which includes 43 companies studied between 2016 and 2021. The factors encompass financial performance and biodiversity impacts, as well as control attributes. Return on Assets (ROA) is calculated as net profit divided by average total assets at time t and $t-1$. Lice Prevalence represents the average number of adult female lice per year. For Lice Treatments Bath, Lice Treatments Feed, and H_{2O_2}, we employ the quantity of API used (in grams) per tonne of live weight equivalent (LWE) as a metric. Escapes are measured as the number of fish escaping from pens on a three-year rolling average basis. All explanatory variables are normalized between 0 and 10 to facilitate comparison and analysis. The control variables include Size (natural logarithm of total assets), Direct Labor (number of employees per calendar year), and Debt (company's total debt to total assets ratio).

5 Methodology

In this chapter, we outline the analytical approaches employed to address our two research questions. Our dataset's panel structure helps us address endogeneity issues and strengthen our ability to identify causal relationships. The first objective is to assess how financial performance is influenced by regulations targeting biodiversity for salmon farming companies. To achieve this, we first utilize the DiD estimator, which enables us to estimate the causal effect of the *Traffic Light System* employed to minimize the sea lice prevalence in Norway. Following the analysis of regulatory impacts, we investigate specific biodiversity impact variables and their significance for financial performance from an international perspective. Since the data generating process is dynamic, we rely on the one- and two-step System GMM estimators. By employing these methodologies, we provide a comprehensive and robust analysis of the interdependencies between biodiversity and financial gains.

5.1 Identifying Treatment Effect: The DiD estimator

We estimate the causal impact of biodiversity regulation on financial returns. In this context, we regard the implementation of the *Traffic Light System* in Norway as a treatment effect. We use companies from other countries (the Faroe Islands, Chile, Australia, and New Zealand) that are not affected by the policy as a control group. Consequently, we examine the relationship by applying the DiD estimator and the following empirical model:

$$Y_{it} = \alpha + \beta_1(\text{Treatment}_i) + \beta_2(\text{Post}_t) + \beta_3(\text{Treatment}_i \times \text{Post}_t) + \gamma \mathbf{X}_{it} + \epsilon_{it} \tag{5.1}$$

where Y_{it} represents the financial performance of firm i at time t measured by ROA. Treatment_i is an indicator variable that equals 1 for firms in the treatment group (i.e., affected by the regulations) and 0 for firms in the control group (i.e., those not affected by the regulations). Post_t is an indicator variable that equals 1 for the post-treatment period and 0 for the pre-treatment period. The interaction term $\text{Treatment}_i \times \text{Post}_t$ captures the causal effect of the regulations on firm's profit, with β_3 being the difference-in-difference estimate.

In this model, X_{it} is a vector of variables that may affect financial performance, such as biodiversity and control variables. γ represents the vector of coefficients associated with these control variables. ϵ_{it} is the error term, capturing unobserved factors that may influence the dependent variable. Lastly, α represents the constant term.

The primary focus of this empirical specification is the coefficient β_3, which captures the causal effect of the local regulation on financial performance. A positive and significant β_3 indicates that the regulations have a positive impact on the dependent variable, while a negative and significant β_3 would suggest that the regulations have a detrimental effect. By employing this empirical specification, we can isolate the causal effect of the regulations on financial performance while controlling for other factors that may simultaneously influence the outcome. This approach allows us to rigorously assess the impact of the *Traffic Light System*.

5.2 Materiality of Biodiversity: Dynamic Panel GMM Estimation

We investigate the relationship between biodiversity variables within salmon farming and financial performance. Building upon the foundational works of Arellano & Bond (1991), Arellano & Bover (1995), and Blundell & Bond (1998), we utilize a dynamic panel System GMM estimation to examine this relationship. Our findings reveal that the data generating process is dynamic, as evidenced in Table 6.2 and Table D.1. Wooldridge (2010) cautions that fixed-effects models may be subject to bias when dynamic relationships exist between current values of explanatory variables and past realizations of dependent variables. Consequently, adopting a dynamic approach enables us to derive unbiased and consistent estimates while addressing the dynamic nature of the underlying economic process, unobserved heterogeneity, and potential endogeneity concerns.

The dynamic panel GMM model can be expressed as:

$$y_{it} = \alpha + \sum_{s} \kappa_s y_{it-s} + \beta \mathbf{X}_{it} + \gamma \mathbf{Z}_{it} + \eta_i + \epsilon_{it} \quad s = 1, ..., p, \tag{5.2}$$

where y_{it} represents the financial performance of firm i at time t, α is a constant term, β and γ capture the effects of biodiversity impact variables and firm characteristics, respectively, η_i denotes unobserved time-invariant firm effects, and ϵ_{it} is the error term. The biodiversity impact factors, $\mathbf{X}_{it}$, are assumed to be functions of past financial performance, firm characteristics, and unobserved firm effects:

$$\mathbf{X}_{it} = f(y_{it-1}, y_{it-2}, ..., y_{it-p}, \mathbf{Z}_{it}, \eta_i) \tag{5.3}$$

In addressing potential biases and endogeneity issues in panel data analysis, particularly, we employ the System GMM as proposed by Blundell & Bond (1998). System GMM combines the first-differenced GMM estimator with the level GMM estimator, improving estimation efficiency by exploiting additional moment conditions not captured by the regular GMM estimator. This approach mitigates endogeneity concerns by utilizing historical firm variables as instruments, thereby addressing biases arising from unobserved factors influencing both dependent and independent variables. Additionally, the System GMM estimator accounts for unobserved heterogeneity in panel data by employing first-differencing to eliminate time-invariant firm-specific effects, circumventing potential biases. Consequently, by employing the System GMM estimator we obtain more reliable and unbiased estimates of the relationships between the variables under investigation.

We implement the System GMM with robust standard error using the one-step approach, which is less sensitive to small sample sizes compared to the two-step approach (Roodman, 2009). As a robustness check, we also employ the two-step System GMM estimator, which offers more precise coefficient estimates at the potential cost of downward bias in standard errors for small sample sizes (Roodman, 2009). We conduct several specification tests, including the Sargan-test for over-identifying restrictions, to assess the validity of the moment conditions, and a test for residual autocorrelation to examine the presence of second-order autocorrelation. The results of these tests are presented in Chapter 6. The findings from the robustness check using the two-step System GMM estimator is given in Table D.1 in the appendix.

6 Results and Discussion

In this chapter, we present and discuss the results from the econometric models. Our study utilizes two distinct empirical models. First, we use the DiD model to identify any statistical evidence that financial performance has been affected by policy changes relating to the aquaculture sector. Second, we investigate the influence and materiality of biodiversity on profitability using the System GMM estimator. By utilizing this model, we account for the dynamic nature of financial performance while controlling for potential endogeneity problems and unobserved heterogeneity in our dynamic panel data. Moreover, we provide a detailed analysis of each biodiversity variable, including escapes, sea lice treatments with antibiotics, sea lice treatment using H_2O_2, and sea lice prevalence. Together, these two empirical models thoroughly examine the complex interrelationships among policy changes, biodiversity and financial performance. In our analysis of the results, we offer novel insights that hold potential implications for future policy decisions. This study enriches the current understanding of the variables affecting financial outcomes within aquaculture, a growing important industry. Our findings, thus, have significant bearings for both theoretical and practical advancements in this field.

6.1 Exploring the Impacts of Biodiversity Regulation on Aquaculture Financial Performance

We employ a DiD estimator to analyze the impact of the *Traffic Light System*, a regulation introduced in Norway's aquaculture industry in 2017 (Norwegian Government, 2017). Although the regulation entered into force in 2017, it was subject to a hearing round in 2016, during which stakeholders were informed about the upcoming regulation and had the opportunity to provide feedback and comments, leading to potential anticipatory effects in the industry (Norwegian Government, 2016). To assess the impact of this new policy, we utilize a novel dataset comprised of salmon farming companies in Norway, Chile, New Zealand, Australia and the Faroe Islands covering the period 2014-2021. In Table 6.1, the results for the DiD model are presented.

Table 6.1: Results Difference in Differences

ROA	Treated	Parallel Trends	Number of observations
Interaction term 2016	-.0207 (.0101)	0.1309	328
Interaction term 2017	-.0241* (.0036)	0.0226	328

Results from the Difference in Differences (DiD) estimator. Coefficients under the column *Treated* are estimates for all the companies in our novel dataset. The treatment being assessed is companies affected by the policy change for the *Traffic Light System* implemented in Norway in 2017. The regulation was publicized in 2016. The column *Parallel Trends* represents the hypothesis that the trends are parallel. As discussed in Equation 5.1, the interaction term is the β_3 coefficient. A plot of the parallel trends model can be found in Figure E.1 in the Appendix. The standard errors for the DiD model are given in parentheses. Note: t statistics are indicated by; $***p < 0.01; **p < 0.05; *p < 0.1$.

To measure the potential impact of the *Traffic Light System* policy on the profitability of the companies, we compare the Norwegian salmon farming firms (our treatment group) with businesses from other regions (Chile, New Zealand, the Faroe Islands and Australia - our control group). As shown in Table 6.1, the DiD model reveals that the parallel trends assumption is valid when considering 2016 as the introduction year, but not for 2017. Given the public knowledge of the regulation in 2016, we argue that this information led to changes in company behavior in that year. In particular, on the practices that are the focus of the aforementioned legislation: lice prevalence and lice treatments. Therefore, we utilize the parallel trends test results from 2016 and the significance results from 2017 to better capture the true effect of the regulation on the industry. By doing so, we account for the anticipatory effects that the announcement of the regulation might have had on the salmon farming companies, providing an accurate assessment of the regulation's impact on biodiversity management practices.

We find that the interaction term for 2017 has a significant and negative sign, as depicted in Table 6.1. Norwegian companies experience a negative impact on financial profitability compared to the control group from Chile, New Zealand, the Faroe Islands and Australia. Our findings suggest that regulations addressing biodiversity conservation exhibit lower profitability in the short-term. By comparing the changes in financial outcomes of treated firms in Norway with those of the control firms, we capture the true policy effects of the Norwegian *Traffic Light System*. Our results align with Kozluk & Zipperer (2015), who find that stringent environmental regulations within certain contexts can harm productivity growth in the short- to medium-term. However, considering the ultimate goal of implementing such policies, in this case, biodiversity protection, there can be some economic costs to achieving these environmental benefits. For instance, Bennear & Olmstead (2008) find that requirements on information disclosure increased drinking water quality in the United States. Moreover, Greaker et al. (2020) suggest that innovation with a high public good content[16] is not adequately adopted by private firms unless backed by targeted government intervention. Hence, policymaking serves as a tool for incentivizing innovation in the aquaculture sector, and it is crucial that governmental bodies recognize the importance of their legislative power in terms of biodiversity conservation.

In the medium- and long term perspective, it is possible that the traffic-light regulation and similar policies can push innovation and strike a balance between private interests and public environmental concerns. Tveterås et al. (2012) and (Asche, 2008) reveal that the salmon farming industry has experienced substantial technical efficiency gains and productivity growth, with some variation across countries attributed to different regulatory environments. The experience from the Faroe Islands, which enforced strict aquaculture veterinary regulations in 2003 (The Government of the Faroe Islands, 2019), serves as a relevant example to compare with our study due to its similarities. The Faroese policy change led to a short-term reduction of production volumes of farmed salmon in the region. Nevertheless, there were several improvements in terms of biodiversity indicators, such as a decrease in the use of antibiotics and lower mortality rates (ICES, 2022). The combination of factors, including the strict policy and unique geographical properties of the Faroe Islands, contributes to the production of a superior product that commands higher prices compared to, for example, Chilean Atlantic salmon. In the period 2016-2019 the average export prices [USD/kg] for farmed Atlantic salmon from Chile and the Faroe Islands were $6.12 and $8.68, respectively (FAO and UN, 2022). Despite a drop in profitability in the first three years, profitability has been consistently high and positive, suggesting that the regulations have not hindered the industry's economic growth (ICES, 2022). By finding the right balance between regulations and market incentives, we expect that the medium to long-term outcomes from the regulation will be more profitable while safeguarding biodiversity.

In sum, our findings indicate that implementing rigorous environmental policies may result in adverse short-term financial outcomes for firms within the aquaculture industry. Nevertheless, drawing upon the comparison of the Faroe Islands' and Chile's aquaculture sector, we argue that such regulatory measures can foster innovation, ultimately yielding positive environmental and financial benefits in the medium to long-term.

6.2 Materiality of Biodiversity on Profitability

Building on our conclusions for policy reforms related to biodiversity, we now shift our focus to the impact of specific biodiversity variables pertinent to the sector. Utilizing the System GMM estimator, we provide a more in-depth understanding of the key variables that influence the financial profitability of companies worldwide. We utilize a novel dataset comprised of salmon farming companies in Norway, Chile, New Zealand, Australia and the Faroe Islands covering the period 2016-2021. This dataset has two years less than the dataset that we use in the DiD estimation. The explanation is our methodology on escapes, utilizing a three year rolling average as described in Chapter 4. Our analysis enables us to ascertain whether specific biodiversity-related variables

[16] Here, high public good content being content that fosters sustainability and constructive initiatives for the general welfare.

are significant for the financial performance of firms engaged in salmon farming globally.

Table 6.2 reports the results from the one-step System GMM. Here, we can identify which of the biodiversity impact variables of our specific System GMM estimator are significant for the financial performance of the companies in our study.

Table 6.2: Results from one-step System GMM estimator

ROA	One-step System GMM
L1. ROA	.4272***
	(.0907)
L1. Escapes	-.0212***
	(.0042)
L1. Sea Lice Treatments Feed	-.0111***
	(.0041)
H_2O_2	.0150**
	(.0063)
L1. Sea Lice Prevalence	.01240*
	(.0068)
L1. Size	-.0720***
	(.0173)
Debt	-.0025***
	(.0009)
Number of observations	215
Sargan	0.0166**
AR(1)	0.0001***
AR(2)	0.3946
Wald Chi-Sq	106.15

This table reports the results of the one-step System GMM estimates. The dependent variable is ROA, the ratio of net income to yearly average total assets, as a measure of financial performance. Explanatory variables include the instrumenting factor ROA at time $t-1$, the measure of escapes at time $t-1$, sea lice treatments feed at time $t-1$, H_2O_2 as an alternative measure of lice treatments at time t, and sea lice prevalence at time $t-1$. The control variables are size (measured by the natural logarithm of total assets at time $t-1$) and debt (measured by the total debt to total assets ratio at time t). Coefficients under the column one-step System GMM are estimates for all the companies in our novel dataset. The standard errors for the one-step model are given in parentheses. We do not find that the biodiversity variable *Sea Lice Treatments Bath* is significant. Therefore, it is not included in this table.
Note: t statistics are indicated by; $***p < 0.01; **p < 0.05; *p < 0.1$.

Firstly, we notice that the lagged ROA is significant, which is aligned with the findings in literature (Hamdi et al., 2022; Ullah et al., 2018). An interpretation of this finding is that the profitability in the previous period influences the next. Persistence in profitability and efficient resource allocation may be a sufficient explanation for the dynamic nature of ROA. Furthermore, we find the controls *Size*, and *Debt* to be significant, which is aligned with literature (Sikveland et al., 2022; Velte, 2017; Fischer & Sawczyn, 2013). We do not find any significant evidence that the biodiversity impact variable *Sea Lice Treatments Bath* has an impact on financial performance.

6.2.1 Escapes

From Table 6.2, the lagged *Escapes* biodiversity factor has a negative impact on financial performance with significance at the $p \leq 0.01$ level. Thus showing that salmon aquaculture firms may experience worse financial results due to fish escapes. This result can be explained by a variety of reasons. The first one is the loss of revenue related to the loss of biomass, which without recapture will not be available for future sales. This loss is estimated to be quite high considering that raising salmon to market size is a costly endeavor that usually takes 2-3 years (Lerøy Seafood Group, 2021). Consequently, escaped fish can lead to reduced productivity and may explain the effect of the lagged variable.

Another factor to consider is the costs related to recapturing escaped fish and regulatory fines. The enforcement of penalties is shared with all the countries under the scope of our study. Its application serves as a measure to penalize the negative environmental harm and threat to biodiversity caused by the escapes (Norwegian Government, 2008; Chilean Government, 2022; Tasmanian Government, 1995; The New Zealand Government, 1996; Government of the Faroe Islands, 2011). These fines have both reputational and financial consequences for the involved parties. It should be noted that these fines may not be imposed immediately, but will rather have a lagged effect when they are executed.

As discussed in Chapter 2 escaped salmon pose a serious hazard to surrounding ecosystems and wild fish populations (Grefsrud et al., 2022). It can lead to genetic alteration of wild salmon populations, which in turn can endanger the long-term longevity of wild salmon populations (Hindar et al., 2006). Moreover, the escaped salmon may carry diseases and parasites that can spread to healthy wild salmons. In Norway, this will have a direct negative effect on financial performance considering that the *Traffic Light System* uses measured lice prevalence on wild salmon to decide whether the production of farmed salmon should be decreased, stay at the same level, or be increased. Hence, the effect of escaped salmon may have a lagged and negative effect on financial performance.

Overall, the number of escaped fish can pose a serious issue for salmon farmers and have a variety of detrimental effects on both biodiversity and the company's financial performance.

6.2.2 Sea Lice Treatments: Antibiotics and Chemicals

Concerning medicinal usage in salmon farming, we assess both feed- and bath treatments for the companies included in our study. First, we discuss our findings relating to medicinal treatment methods using antibiotics and chemicals both through feed and bath. Taking into consideration the biodiversity aspect of not using antibiotics, we also present our findings related to alternative bath treatments, specifically focusing on H_2O_2-usage.

We do not find any evidence that bath treatments using antibiotics and chemicals are significant, but we uncover that the lagged medicinal treatments used in feed are significant for financial performance at the $p \leq 0.01$ level. For the biodiversity impact variable *Sea Lice Treatments Feed*, we find that the factor has a negative impact on financial returns. Concerning the use of sea lice treatments, higher expenses associated with utilizing more medicine may be one of the main reasons why increased fish feed treatments can explain inferior profitability. Greater API usage per LWE is a good proxy for roughly comparing the companies' medicinal usage (of antibiotics and chemicals). More intense usage may also indicate a low Feed Conversion Rate (FCR) and a high level of diseases within the enterprise, potentially indicating ineffective operations management.

A possible explanation for the significance of lice treatments in our findings may be attributed to the market value differences between salmon raised with fewer antibiotics and medicinal treatments, as compared to those raised under stricter policies. As discussed previously, the Faroe Islands implemented comprehensive and strict aquaculture veterinary regulations in 2003, leading to farmed salmon being completely free of antibiotics (The Government of the Faroe Islands, 2019). In contrast, Chile's salmon farmers used 463.4 metric tons of antibiotics in 2021 (Molinari, 2022b). In 2016-2019 the Faroe Islands yielded higher average export prices [USD/kg] for farmed Atlantic salmon compared to Chile (FAO and UN, 2022). Sagar et al. (2023) states that the role of food chains is substantial in stopping the spread of AMR[17] worldwide. Animal protein raised without antibiotics is assessed to be as healthier and more sustainable, thus it is generally considered to be worth more than their counter-parties. Campaigns such as "Raised Without Antibiotics"[18] highlight potential pitfalls of the high usage of antibiotics in protein production are a powerful driver of this discount effect. These kinds of campaigns have proven to be quite effective; for example, such movements drove the replacement of antibiotics with alternative treatment by salmon farming businesses in Norway (Norwegian Seafood Council, 2020).

[17] AMR: Anti-Microbial Resistance

[18] "Raised Without Antibiotics" is a label or certification used to indicate that animals raised for food production, such as poultry or livestock, were not given antibiotics during their lifetime (NSF, 2023).

From a long-term perspective, the implications of higher medicinal usage in aquaculture, particularly in the context of antibiotics used in sea lice treatments can affect financial profitability. Grefsrud et al. (2022). The use of antibiotics can contribute to the proliferation of antibiotic-resistant bacteria, posing risks to both environmental and human health (Sagar et al., 2023). In the long run, companies that fail to reduce their antibiotic usage may lose competitiveness in the global market. For instance, the Chilean salmon farming industry has faced criticism in recent years due to the overuse of antibiotics and environmental damage to surrounding biodiversity. New US trade regulations require countries to demonstrate that their fishery and aquaculture activities are equivalent in effectiveness to the US Marine Mammal Protection Act, or risk losing the permit to export seafood products to the US market (Williams et al., 2016). As such, adherence to sustainable practices and reduced antibiotic use is becoming increasingly crucial for maintaining market competitiveness and ensuring long-term success in the aquaculture industry.

Overall, while using the appropriate amount of treatments is necessary for the health and growth of farmed salmon stocks, over-usage can have detrimental effects on biodiversity, while also being a driver of costs and lost revenue for the companies.

6.2.3 Sea Lice Treatments: Hydrogen Peroxide

In later years the use of alternative treatments in baths such as H_2O_2 have become more widespread due to abstaining from antibiotics usage and lice becoming resistant to other chemicals (Overton et al., 2018). We find significant results at the $p \leq 0.05$ level, suggesting that this type of treatment is associated with higher profitability of aquaculture companies. In contrast to the other variables, we find that H_2O_2 treatments impact the financial performance of the year in which they are applied.

The economic impact of sea lice on the aquaculture industry is significant, with costs reaching US$436 million for the Norwegian sector in 2011 (Abolofia et al., 2017) and likely being much higher today. By reducing the prevalence of sea lice, farmers may be able to improve the overall health of their fish, decrease mortality rates, and ultimately increase yields, leading to enhanced financial performance. Aligned with the findings of Velte (2017), which assess whether financial returns are positively correlated with CSR, management who focus on CSR matters tend to efficiently manage the operations of the company, which in turn can give positive financial returns for the company.

Another possible explanation for our results is related to the biodiversity perspective, where the usage of H_2O_2 as an alternative treatment method is less harmful to the environment and may lead to better conditions for aquaculture operations in the long term. H_2O_2 is frequently used to treat bacterial infections, sea lice, and other parasites (Overton et al., 2018). However, it is crucial for the industry to maintain its efficacy, as sea lice can develop resistance over time (Overton et al., 2018). Notably, H_2O_2 rapidly breaks down in water and oxygen, which are properties that have led to increased usage by environmental agencies during pollution incidents to raise oxygen levels for fish and prevent suffocation (Scotland, 2023). This may result in a lower likelihood of disease outbreaks, further contributing to increased yields and consequently higher financial gains.

Lastly, treating fish with H_2O_2 may make the product more marketable, explaining why we find significance at the time the treatment is applied. As discussed previously, this can be due to the possibility that some customers may prefer to buy fish that has been treated with H_2O_2 which is a substitute to other conventional treatment methods that involve antibiotics. By demanding a premium for their products, farmers may be able to improve on financial performance compared to their competitors. The usage of H_2O_2 in salmon farming may also have downsides, including the potential for harmful impact on surrounding ecosystems and the health of the fish if used incorrectly. Ultimately, the benefits and cons of employing treatment in salmon farming will rely on a range of parameters specific to each farming operation. Overall, we find that the usage of H_2O_2 has a positive effect on the financial performance of the companies that are included in our study.

6.2.4 Sea Lice Prevalence

In our analysis, we find a positive relationship between *Sea Lice Prevalence* and financial performance. The result is significant at the $p \leq 0.1$ level. This association, at first sight, may appear counter-intuitive, as one might expect higher sea lice prevalence to negatively impact financial performance due to the adverse effects on fish health, productivity, and costs associated with treatments. However, several other factors appear to counteract this intuition.

Firstly, we argue that reporting bias can be an important factor contributing to the observed positive relationship. In line with the findings of Nygård (2020), which suggest that higher standards of sustainability reporting can positively impact financial performance, we hypothesize a potential bias in the reporting of lice prevalence by the companies in our study, as lower reported lice prevalence could be viewed as a measure of sustainability. In our case, we argue that enterprises with better profitability may have more transparent reporting and monitoring practices, leading to higher reported sea lice prevalence compared to companies with less rigorous reporting. In this case, the positive relationship between sea lice prevalence and financial performance may not reflect a true causal relationship but rather a difference in reporting practices.

Furthermore, companies facing higher sea lice prevalence might be more likely to innovate and adopt new technologies or management practices to combat this issue. According to Asche (2008); Tveterås et al. (2012), there have been substantial technical efficiency gains and productivity growth within the industry. As a result, companies that are able to innovate and become more efficient have a greater chance of financial success over time, driven by their adaptive capacity and resilience in the face of challenges.

6.2.5 Robustness Check: two-step System GMM

To ensure the robustness of our empirical results of the one-step System GMM estimator we implement the same model with the two-step System GMM estimator, given in Table D.1. As mentioned in Chapter 5, one of the main reasons for using the one-step as main results and two-step as robustness check is dependent on the characteristics of our dataset. According to (Roodman, 2009), the one-step estimator is better suited for handling datasets with a smaller sample size . Nevertheless, by using the two-step System GMM estimator as a robustness check, we can address some of the limitations inherent in the one-step estimator, such as inefficiency and finite sample bias. This additional analysis strengthens the validity of our findings and provides more reliable evidence for the relationship between biodiversity and financial performance within the salmon farming industry. Consequently, our research can offer valuable insights for policymakers and industry stakeholders who are working to develop sustainable and viable business practices in the context of biodiversity.

The two-step System GMM results corroborate our earlier discoveries by confirming the negative sign and strong statistical significance of escapes. Additionally, it provides evidence that escapes are negatively related to financial performance in the salmon farming industry. Furthermore, we uncover that sea lice prevalence and H_2O_2 remain significant with a positive sign. These results highlight the importance of considering the impact of biodiversity factors on the industry's financial performance.

7 Conclusion

The salmon farming industry is increasingly recognized for its vital role in alleviating the pressures of overfishing and the subsequent depletion of global fish stocks. By providing a more controlled and sustainable alternative to traditional fishing methods, salmon aquaculture holds significant potential in contributing to the global green transition. However, as the industry expands and concerns about its environmental impacts arise, introducing and enhancing policies and regulations targeting biodiversity preservation and environmentally responsible practices within the industry become crucial.

In recent decades, the nexus between ESG and corporate financial performance has gained increasing recognition among stakeholders, leading to the integration of non-financial dimensions, such as environmental factors, into financial decision-making processes. However, the risks associated with biodiversity loss have been largely overlooked. This oversight is particularly problematic for industries deeply reliant on ecosystem services, and the implications can be even more severe when these industries harm these services, as is the case with salmon aquaculture. This study offers a novel perspective on the complex interplay between biodiversity within aquaculture and financial performance. We identify material biodiversity impact variables and construct two novel panel datasets, one consisting of 40 salmon farming companies for the 2014-2021 period and the other consisting of 41 companies and an additional biodiversity variable between 2016-2021. We investigate the implications of regional policies intended to safeguard biodiversity, looking at how these measures affect financial performance. Moreover, we look at industry-specific biodiversity impact indicators and assess how these variables affect profitability.

Our empirical strategy is twofold. First, We analyze the impact of biodiversity policy, specifically the "Traffic Light System" implemented in Norway, on the aquaculture industry's profitability using a DiD estimator. We find that the regulation has negatively affected the profit of companies treatment group. Our findings suggest that policies with stronger commitments to biodiversity conservation exhibit lower financial performance for the affected companies in the short-term. Considering the environmental aspect of implementing such policies, there are benefits in terms of conservation of biodiversity and negating adverse environmental impacts. By penalizing companies that are performing poorly on lice counteraction measures, the legislative body makes it harder to compete with competitors worldwide from a financial perspective. In the medium and long-term, however, these regulations could push innovation and strike a balance between private interests and public environmental concerns. For instance, in 2003, the Faroe Islands implemented one of the most comprehensive and stringent aquaculture veterinary regulations, eliminating the use of antibiotics. Nevertheless, despite a drop in profitability in the first three years, profitability has been consistently high and positive, suggesting that the regulations have not hindered the industry's economic growth. Aligned with literature, we suggest that private firms do not adequately adopt innovation with a high public good content unless backed by targeted government intervention (Greaker et al., 2020). Hence, policymaking serves as a tool for incentivizing innovation in the aquaculture sector, and it is crucial that governmental bodies recognize the importance of their legislative power in terms of biodiversity conservation. Therefore, we expect that, in the medium to long term, finding the right balance between regulations and market incentives will lead to a more sustainable and profitable aquaculture industry that safeguards biodiversity.

In the second part of our empirical strategy, we use the one-step System GMM estimator. We use key risk variables identified by research and industry that serve as indicators for significant biodiversity impact factors on financial performance in aquaculture operations. We find that more profitable firms have better environmental performance. In general, businesses with greater financial performance typically experience fewer fish escapes and use less antibiotics and chemicals in their treatment methods. Additionally, companies that successfully implement alternative treatment methods without antibiotics, such as H_2O_2, for sea lice control exhibit higher returns compared to their counterparts. The robustness check further validates our findings, that the connections between financial performance and biodiversity impact variables remain valid even after accounting for the effects of using a two-step estimator. The evidence supports that the profitability of companies engaged in salmon aquaculture depends on their performance on biodiversity issues.

In conclusion, our study provides an understanding of the interplay between biodiversity and financial performance in the aquaculture industry. The findings from the DiD estimator highlight the importance of striking the right balance between regulations and market incentives, while the results from the one- and two-step System GMM emphasize the significance of biodiversity variables for financial performance. These results underscore the need for effective policymaking and innovation to ensure the long-term viability of the aquaculture industry while prioritizing the conservation of biodiversity. By acknowledging the interconnected nature of biodiversity and financial performance, decision-makers, industry stakeholders, and investors can support sustainable practices in the context of salmon farming that benefit both the environment and the economy.

There are three possible trajectories for future research that emanate from this study. Firstly, the ongoing advancement in biodiversity measurement will potentially yield more refined data. By increasing the frequency of data gathering, expanding the scope of companies involved, and creating a global standard for assessing biodiversity risks, future studies can stand to benefit from these advancements by further refining the dataset utilized in this study, creating even sharper results. Second, we suggest including additional direct impacts variables like eutrophication and waste production. Third, exploring indirect impacts on biodiversity, such as electricity usage, greenhouse gas emissions, area occupation, noise, and impact from feed production, presents an opportunity for future research. These factors will require a framework capable of meaningfully assess and score different companies. Investigating these factors can provide additional perspectives on the relationships between financial performance and biodiversity impact in the aquaculture industry.

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A Policy: Traffic Light System

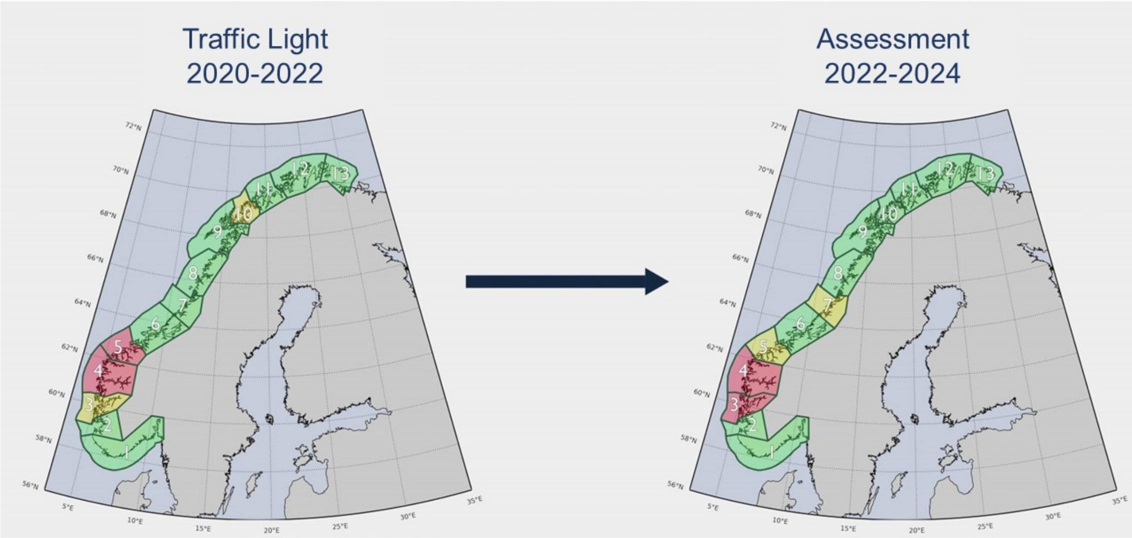

Figure A.1: Overview of the *Traffic Light System*. The Norwegian coastline is divided into 13 production areas. Each production area is assessed with either: low, moderate or high risk, with regards to the level of sea lice prevalence on wild salmon stocks. Source: Norsk Fisk (2022).

B Companies Included in Study

Table B.1: Overview of Companies in Scope

Company	Country	Privately or publicly traded
AquaChile S.A.	Chile	Private
Blumar S.A.	Chile	Public
Camanchaca S.A.	Chile	Public
Multiexport S.A.	Chile	Public
Bakkafrost ASA	Faroe Islands	Public
Tassal Tasmanian Salmon	Australia	Private
New Zealand King Salmon Co Ltd	New Zealand	Public
Grieg Seafood ASA	Norway	Public
Mowi ASA	Norway	Public
Lerøy Seafood Group ASA	Norway	Public
Salmar ASA	Norway	Public
Cermaq Norway AS	Norway	Private
Nova Sea AS	Norway	Private
Nordlaks Oppdrett AS	Norway	Private
Alsaker Fjordbruk AS	Norway	Private
NRS Farming AS	Norway	Private
Sinkaberghansen AS	Norway	Private
Salmonor AS	Norway	Private
Bremnes Seashore AS	Norway	Private
Eidsfjord Sjøfarm AS	Norway	Private
Måsøval AS	Norway	Public
Firda Sjøfarmer AS	Norway	Private
Blom Fiskeoppdrett AS	Norway	Private
Eide Fjordbruk AS	Norway	Private
Erko Seafood AS	Norway	Private
Bolaks AS	Norway	Private
Bjørøya AS	Norway	Private
Ellingsen Seafood AS	Norway	Private
Hofseth Aqua AS	Norway	Private
Lingalaks AS	Norway	Private
Lovundlaks AS	Norway	Private
Flakstadvåg Laks AS	Norway	Private
Emilsen Fisk AS	Norway	Private
Tombregruppa	Norway	Private
Osland Havbruk AS	Norway	Private
Egil Kristoffersen og Sønner AS	Norway	Private
Wilsgård Fiskeoppdrett AS	Norway	Private
Kobbevik og Furuholmen Oppdrett AS	Norway	Private
Kleiva Fiskefarm AS	Norway	Private
Gildeskål Forskningsstasjon AS	Norway	Private
Steinvik Fiskefarm AS	Norway	Private
Salaks AS*	Norway	Private
Sulefisk AS	Norway	Private

In this table, we present a summary of the companies included in our study. The first column lists the names of the companies being analyzed, providing a clear scope of the firms under consideration. The second column indicates the primary country in which each company operates and from which we have gathered data. It is important to note that some of these companies may have additional operations in other countries that are not accounted for in our dataset. The third and final column identifies the ownership structure of each company, specifically whether it is a privately-held or publicly-traded firm. *Salaks AS is not included in the 2014 data set.

C Summary Statistics: Dataset 2014-2021

Table C.1: Descriptive Statistics (2014–2021)

Variable	Obs	Mean	Std. Dev	Min	Max
ROA	328	13.67	11.09	-16.22	58.39
Lice Prevalence	328	9.17	1.86	0.00	10.00
Lice Treatments Bath	328	9.23	1.46	0.00	10.00
Lice Treatments Feed	328	9.46	1.31	0.00	10.00
$H_2 0_2$	328	9.11	1.61	0.00	10.00
Direct Labour	328	796.39	2275.08	5.50	14866.00
Size	328	12.15	1.25	10.20	15.75
Debt	328	39.83	25.95	0.00	89.88

This table presents the summary statistics for our dataset, which includes 41 companies studied between 2014 and 2021. The variables include financial performance, explanatory variables, and control variables. Return on Assets (ROA) is calculated as net profit divided by average total assets at time t and $t-1$. Lice Prevalence represents the average number of adult female lice per year. For Lice Treatments Bath, Lice Treatments Feed, and H_2O_2, we employ the quantity of API used (in grams) per tonne of live weight equivalent (LWE) as a metric. All explanatory variables are normalized between 0 and 10 to facilitate comparison and analysis. The control variables include Size (natural logarithm of total assets), Direct Labour (employees per calendar year), and Debt (company's total debt to total assets ratio).

D Two-step System GMM

Table D.1: Results from two-step System GMM

ROA	Two-step System GMM
L1. ROA	.4136***
	(.1346)
L1. Escapes	-.0208***
	(.0033)
L1. Sea Lice Treatments Feed	-.0089
	(.0059)
H_2O_2	.0121*
	(.0069)
L1. Sea Lice Prevalence	.0109**
	(.0051)
L1. Total Assets	-.0616***
	(.0228)
Debt	-.0026***
	(.0011)
Number of observations	215
Sargan Test	0.0253**
AR(1)	0.0032***
AR(2)	0.3626
Wald Chi-Sq Test	90.80

This table reports the results of the two-step System GMM estimates. The dependent variable is ROA, the ratio of net income to yearly average total assets, as a measure of financial performance. Explanatory variables include the instrumenting variable ROA at time $t-1$, the measure of escapes at time $t-1$, sea lice treatments feed at time $t-1$, H_2O_2 as an alternative measure of lice treatments at time t, sea lice prevalence at time $t-1$, and total assets at time $t-1$. The control variable is debt, measured by the total debt to total assets ratio at time t. Coefficients under the column two-step System GMM are estimates for all the companies in our novel dataset. The standard errors for the two-step model are given in parentheses. The biodiversity variable *Sea Lice Treatments Bath* is not significant and thus not included in this table.
Note: t statistics are indicated by; $***p < 0.01; **p < 0.05; *p < 0.1$.

E DiD Estimator: Trend Plot

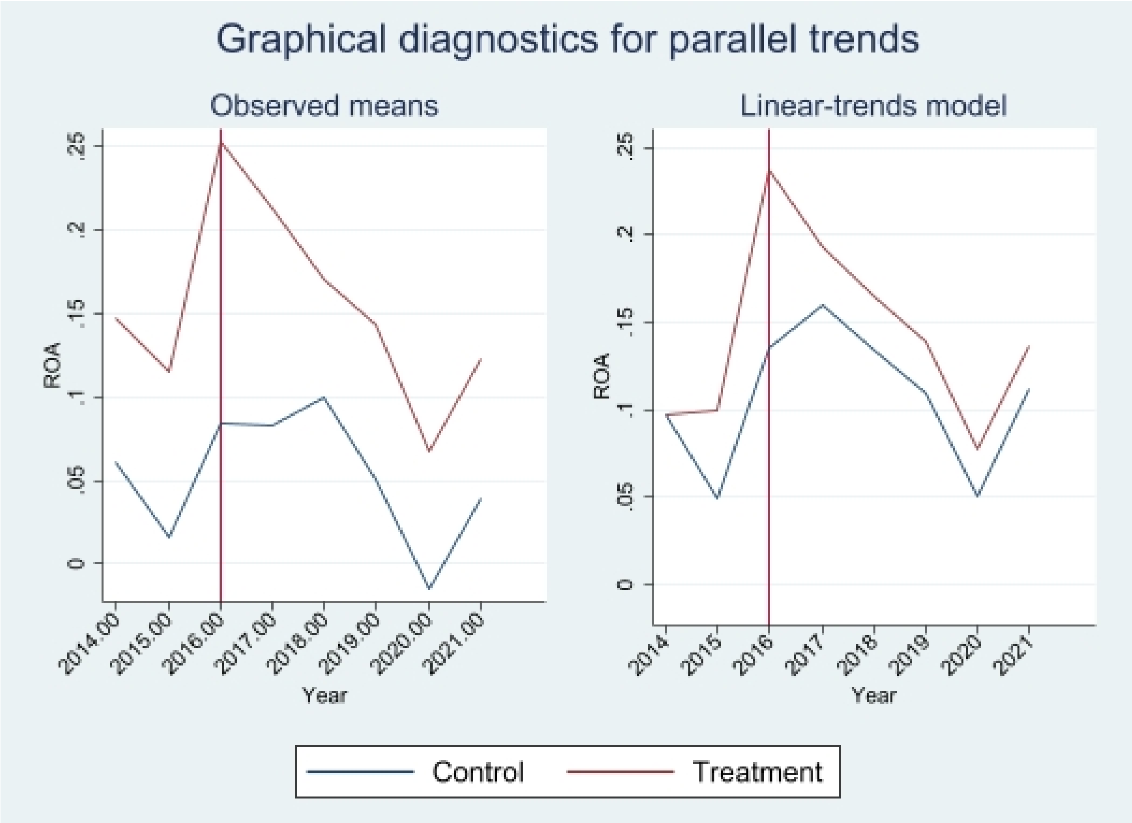

Figure E.1: Difference-in-differences trend plot. Illustration the shows how the implementation of the Traffic Light System affected the treatment group (Norwegian salmon farming companies), compared to the control group (salmon farming companies from Faroe Islands, Chile, New Zealand and Australia). The figure illustrates both the observed means, in addition to the linear-trends model. As seen in Table 6.1 the p-value for parallel trends in 2016 was $p = 0.1309$ implying that we can accept the H0-hypothesis of having a parallel trend prior to the introduction of the treatment.

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