How Can Innovative Post Smolt Strategies Revolutionize Sustainability in Salmon Farming?

Master Thesis

by
Andrea Sørbø Engeseth and Julie Ertzgaard Sangnes
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Supervisor:
Geir H. Bjønnes

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This is our thesis for the MSc in Business program with a major in Sustainable Finance at BI Norwegian Business School. The journey of writing this thesis has been both educational and challenging. It has taken us months of hard work, but we are delighted to finally present our completed work.

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Abstract

This thesis evaluates the effectiveness of Closed Containment Systems (CCS) and Recirculating Aquaculture Systems (RAS) in enhancing the sustainability and economic possibilities of the Norwegian salmon industry in the Western Norway region. Utilizing data from Ovum AS for the post smolt stage and advanced simulation modelling, the study demonstrates that employing larger post smolt sizes to the open net farming practice can dramatically reduce mortality rates by up to 40% and decrease the frequency of sea lice treatments by over 80%.

These improvements significantly support fish welfare and reduce the environmental footprint of aquaculture practices. Furthermore, the adoption of CCS and RAS not only optimizes operational efficiencies but also elevates profitability by enhancing operational margins through better maximum allowed biomass utilization and reduced operational risks. The findings advocate for a strategic shift in practices involved in farming Atlantic salmon, suggesting that the integration of cutting-edge technologies in post smolt strategies is imperative for achieving sustainable growth and resilience in the industry. This research provides compelling evidence that advanced aquaculture systems are essential for the future sustainability and economic success of salmon farming in Norway.

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List of Abbreviations

Smolt Salmon that have undergone what is called ”smoltification”, transitioning from living in freshwater to being capable of surviving in saltwater.

Post smolt Salmon that have been acclimated to seawater for an extended period and have reached a size of up to 1 kg before being released to open net farming.

CCS Closed Containment System: A floating closed structure that shields the fish from the surrounding environment.

RAS Recirculating Aquaculture Systems: A land-based aquaculture facility that recycles the water used in fish production.

EGG The EGG Technology as a Closed Containment System: An enclosed technology for industrial fish farming made by Ovum AS.

MAB Maximum Allowed Biomass: The maximum permissible biomass living weight a fish farmer can have in the pen at any given time.

MAB-year Maximum Allowed Biomass per year: The ”MAB-year” is computed by aggregating the weekly total biomass kg live in sea and adjusting this total over a period of 52 weeks.

HOG Head-on-gutted: The salmon has been starved, bled and gutted with its head on. The fish’s weight is approximately 82% of the salmon’s living weight.

WFE Whole Fish Equivalence: The weight proportion of a live swimming salmon after it is bled and starved, often corrected by a weight loss of -6.7%.

eFCR Economic Feed Conversion Ratio: The amount of feed given to a generation divided by the net surviving live biomass gained at harvest.

bFCR Biological Feed Conversion Ratio: The amount of feed given to a generation divided by the total gained biomass at harvest, including the gained weight of the non-surviving fish.

FFE The Fish Farming Economics Model: The model provided by Knut Senstad in order to help us with our calculations.

Superior grade The salmon is flawless, defect-free, skin is not wounded, has fine fins, and normal body shape.

Ordinary grade The salmon has minor flaws.

Production grade The salmon has wounds on the skin, and hence, it cannot be exported.

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1 Introduction

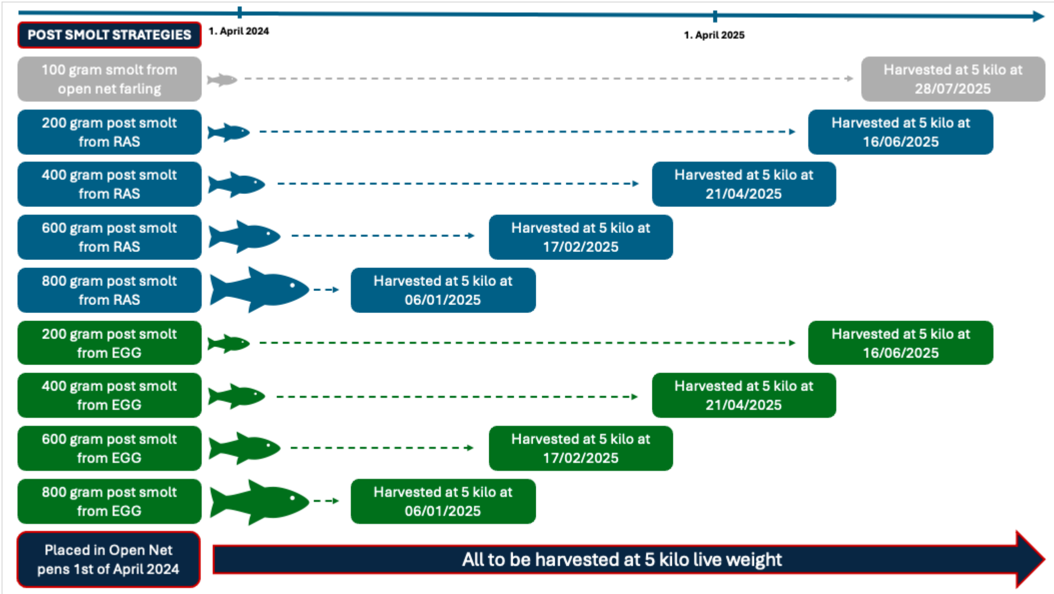
1.1 Introduction to the Problem

This master thesis aims to compare the effectiveness of releasing Atlantic salmon post smolt of varying sizes in open net locations in the Western region of Norway, utilizing conventional sea facilities alongside post smolt from both closed containment systems (CCS) and from recirculating aquaculture systems (RAS). We define post smolt as a young salmon that has recently transitioned from freshwater to seawater, typically reaching a size between 100 grams and 1 kilogram. Smolt is the even younger salmon that has undergone smoltification, a physiological process enabling it to transition from freshwater to being capable of surviving in seawater.

Initially, we will release a conventional generation of one million 100 gram smolts in open net pens (referred to as our benchmark), followed by a comparative assessment involving four generations of post smolt sizes of 200, 400, 600, and 800 grams, all sourced from land-based RAS facilities. This analysis will further be benchmarked against four similar generations of post smolts originating from the CCS technology illustrated by EGG, made by Ovum AS. All 9x generations will be released on April 1st 2024, ensuring uniform operating conditions in the Western Norway region. All 9x generations are farmed until the harvest live weight of 5kg is reached. In this analysis, we have accessed data from Ovum AS and utilized the fish farming economic model developed by biologist Knut Senstad. This approach clearly delineates the distinct differences between various production methods. Our rationale is grounded in the belief that, at present, these new systems utilize staff, assets, and farming permits more effectively in conjunction with open-net pens, compared to conventional smolt of 100 gram released directly into open-net pens. This thesis hence seeks to address the following research question outlined below:

How can implementing CCS and RAS technologies in post smolt strategies enhance the sustainability and profitability of the Norwegian aquaculture sector? Specifically, will these technologies reduce mortality rates, increase robustness, and improve productivity, thereby impacting operational margins and allowing farmers to utilize their farming permits more effectively with improved fish welfare and sustainability goals?

Figure 1: Our Research Question



The Norwegian salmon aquaculture industry stands as one of the world's most efficient and sustainable producers of protein according to the Coller FAIRR index, playing a pivotal role in the growth of the food production sector (Norwegian Seafood Council, 2021). Research indicates that by 2050, food systems must address the needs of a population of 9,3 billion people, requiring an increase of over 60% in current production levels (Food and Agriculture Organization of the United Nations, 2023). The aquaculture industry emerges as a promising candidate to address the escalating needs of the world's expanding population for healthier food, with typically a lower carbon footprint, coupled with reduced impact on biodiversity (NOAA Fisheries, 2020). The aquaculture industry boasts a minimal CO2 footprint and a low feed conversion ratio compared to traditional agriculture. The greenhouse gas emissions per kilogram of beef are 7.3 times higher than for farmed fish, highlighting the potential for farmed fish to become the preferred protein source in the future (Ritchi et al., 2022). These attributes position aquaculture as a robust model for the future production of proteins, aligning with the evolving requirements for sustainable and efficient food sources. However, as the demand for aquaculture products rises, ensuring the industry‘s resilience and sustainability becomes paramount. How can the aquaculture sector adapt and innovate to meet this growing demand while maintaining its commitment to sustainability?

As we delve into the complexities of modern aquaculture practices, incorporating new technologies becomes imperative for achieving enhanced efficiency and sustainability. Innovations like CCS represent a paradigm shift in aquaculture, minimizing environmental impacts by confining fish within controlled environments (Nilsen et al., 2017). Similarly, the advent of land-based farming with integrated RAS technology offers a novel approach by bringing aquaculture onto the mainland. This technology eliminates concerns associated with marine environments, enabling farmers to exercise greater control over various parameters. To reduce the serious water pollution from the fast-growing aquaculture industry, it's essential to develop better systems that use water more efficiently and have less environmental impact (Zhang et al., 2011). Land-based systems facilitate the implementation of advanced water recirculating technologies (RAS), reducing water consumption and waste discharge (Institute of Marine Research, 2023b).

Traditionally, the salmon farming industry structured around the open-net strategy faces challenges such as higher mortality rates, reduced fish welfare, susceptibility to diseases, and environmental concerns (Nilsen et al., 2020). However, integrating advanced technologies such as CCS and RAS holds promise in mitigating some of these challenges. These advancements offer the potential to revolutionize aquaculture practices, enhancing efficiency, sustainability, and resilience to environmental pressure. Furthermore, they can be effectively integrated with existing open-net technologies to enhance overall system performance. Lastly, these technologies could serve as strategic tools for regulatory bodies, guiding and motivating stakeholders towards achieving broader environmental and economic objectives, including the potential for further scaling up the salmon industry.

This study is poised to make a substantial contribution to the growing body of research on sustainability and technological advancements within the Norwegian salmon aquaculture industry. By demonstrating how to effectively leverage CCS and RAS in post smolt strategies, we highlight the underutilized economic potential of especially CCS in this context. Moreover, our research attempts to provide practical insights into the effective utilization of emerging technologies in aquaculture operations, addressing key challenges and opportunities in the field. Through rigorous analysis and empirical factual evidence, we aspire to provide actionable recommendations for industry stakeholders, promoting the adoption of innovative strategies to drive sustainable growth and resilience in aquaculture practices. This master thesis underscores the necessity of conducting region-specific, fact-based analyses before formulating significant strategies concerning any smolt/post smolt operations. It highlights the importance of aligning these strategies with the cost structures prevalent among farmers in each region and fish health concerns. Furthermore, our findings advocate for thorough evaluation and benchmarking of post smolt strategies, emphasizing the necessity to move beyond traditional KPIs towards metrics that more accurately reflect true performance and value when new strategies are implemented.

2 The Aquaculture Industry

The exceptional growth and economic success of the Norwegian salmon farming industry stand as a testament to industrial innovation (Barentswatch, 2023). From its inception as a coastal family enterprise, the industry has grown into a sophisticated large-scale operation over the past five decades. The production volume has increased from its origins, demonstrating a thousandfold increase, culminating in 2023 with a record export of 1.4 million tonnes of salmon, valued at NOK 122.5 billion - a 16% increment from the previous year, and accounting for a staggering 71% of Norway's total seafood exports (Norwegian Seafood Council, 2024).

2.1 The Value Chain

Our thesis delves into the operational complexities of the Norwegian salmon industry's value chain, particularly the role of post smolt integration from technologically advanced CCS and RAS platforms. Salmon undergo two distinct life stages; the initial phase is dedicated to developing the egg into a smolt, and the subsequent stage is focused on growth into harvest-ready salmon, often targeted as a 5.0 kg live fish. Typically, Atlantic salmon commence their life cycle in freshwater environments, undergoing smoltification over 12 to 18 months until reaching an approximate weight of 100 grams. These traditional smolts are then transferred to seawater and are placed in open net pens, wherein throughout 12 to 18 months they grow to harvest weight, influenced by factors such as smolt weight, water temperature, health, and feeding conditions (Institute of Marine Research, 2019).

By challenging the traditional practice of moving 100 gram smolts directly to open pens, our thesis posits an examination of whether an extended farming period in CCS or RAS for post smolts could translate to greater sustainability for the industry. This examination is especially pertinent given the recent concerns about mortality rates and negative fish health trends as reported by the Norwegian Veterinary Institute (Sommerset et al., 2024). It also seeks to determine if such an innovative approach can mitigate these challenges and how this may negatively or positively impact the farming economy.

2.2 The Post Smolt Evolution

The concept of ”post smolt”, which denotes the transition from freshwater to seawater tolerance (CtrlAqua, n.d.), has driven many innovations in Norwegian salmon farming. Our focus is to evaluate how an extended post smolt period in controlled environments before sea transfer can mitigate exposure to marine threats such as sea lice and diseases. Grieg Seafood ASA exemplifies this shift with transparent, data-driven reports detailing their progressive post smolt strategy and investments aimed at elevating the smolt transfer weight to approximately 800 grams by 2025, thereby accentuating biological advantages like mortality reduction and sea lice management. They reinforce their strategy by emphasizing a robust 12-month revolving survival rate of 94% (Grieg Seafood, 2024). Alongside Grieg Seafood ASA, a number of other publicly listed companies, such as Mowi ASA, Salmar AS, and Måsøvald AS, as well as numerous private entities, are actively investigating the advantages of employing strategies for post smolt salmon growth. Notably, the majority of these organizations are concentrating on the development of their post smolt strategies utilizing the RAS platform instead of the CCS alternative. This preference for RAS over CCS is significant, reflecting a gap in the production methods used for post smolt (Dalsgaard et al., 2013). In 2020, Bjørndal and Tusvik presented a comparative analysis in their article, examining the on-growing of traditional 100 gram smolts against the on-growing of 500 and 1000 gram post smolts on land. Their findings revealed that land based on-growing of post smolts proved to be more profitable, which supports the industry's increasing inclination towards utilizing RAS for post smolt cultivation (Bjørndal and Tusvik, 2020).

Norwegian technological companies such as FishGlobe AS, Hauge Aqua AS, LetSea AS, Aquafarms Equipment AS, and Fizzk AS, are progressively integrating CCS technologies. However, the absence of exclusive reliance on post smolt from CCS or RAS is attributed to the limited availability of good enough sustainability performance data and economic analyses of such farming methods. This thesis seeks to fill that gap by leveraging the EGG technology from Ovum AS to simulate various post smolt strategies, applying their empirical biological and economic data from its first two post smolt EGG generations released to open net pens in the Western Norway region in 2023. Our aim is to explain the true cost and benefits of varying EGG post smolt sizes, contributing to a deeper understanding of their potential impact on the Norwegian salmon industry. The development of the EGG technology is still ongoing, where improvements and larger-scale units may become commercially available.

2.3 The Western Norway Region

Our thesis focuses on the aquacultural dynamics in the Western Norway region, a cornerstone of Norway's salmon industry. The region is segmented into four primary production areas: P2 - Ryfylke, P3 - Karmøy to Sotra, P4 - Nordhordaland to Stadt, and P5 - Stadt to Hustadvika. With a recorded total average monthly standing biomass of 218,114 tonnes and a harvest volume of 461,291 tonnes in 2022 (Appendix, Table 1), the region serves as a significant contributor to the nation's salmon aquaculture output. However, Western Norway confronts an annual fish loss ranging between 17.0% to 25.5%, which is significantly higher than the national average of 16.0% (Sommerset et al., 2024)(Appendix, Figure 1).

We set forth with the premise that a 20.0% cumulative generation loss within this region is a reasonable estimate, yet we remain aware of the fluctuations inherent in this figure. Our study posits a baseline generation mortality rate of 16.0% where sea lice mitigations' impact creates an additional 4.0% loss attributable to mechanical treatment effects on the generation (Appendix, Input 2). This rate forms the basis of our assessment of the current mortality benchmarks for fish farms in Western Norway where traditional 100-130 gram smolts are released. For the larger post smolts that spend less time in open nets, a similar percentage-wise calculation reduction is applied to estimate their decrease in baseline mortality, reflecting their percentage reduced time in the sea compared to our benchmark 100 gram generation (Appendix, Table 3). Each post smolt generation may also benefit from a reduced need for sea lice treatments. This advantage leads to fewer additional losses when compared to the benchmark generation, which incurs an extra 4.0% in accumulated losses for the smallest post smolt stages, before reaching the harvest weight of 5 kg live weight. This methodology is identical for each of the post smolt initial weights sourced from either RAS or CCS.

The Institute of Marine Research's annual risk report underscores the high-risk profile associated with the current fish health condition in the Western Norway production regions (Institute of Marine Research, 2023a). This acknowledgement drives our study into alternative farming and production strategies that could centre the regional value chain toward improved survival rates and enhanced sustainability. Our methodology is tailored not only to Western Norway, but can also be extended to other production regions and abroad, representing a universal model for strategic advancement in the aquaculture sector. By cultivating larger post smolts in controlled RAS and CCS environments, we intend to systematically explore and quantify the potential reduction in mortality rates, which has been proved in previous research as well (Nilsen et al., 2020). Our fact-based investigation aims to shed light on the potential uplift in productivity per farming permit, particularly within a region troubled by challenging fish welfare conditions (Asche et al., 2013) and how this may influence the fish farming economic output.

2.4 Sustainability in the Industry

The need for sustainability in fish farming has never been more important. With the industry confronted by multifaceted challenges including escalating mortality rates, pervasive sea lice infestations, disease vulnerability, fish escapes, and intensifying environmental examination, the need for systemic changes is clear (Nilsen et al., 2020). Notably, mortality rates increased dramatically in 2023, with seven million more farmed salmon lost than in the previous year - a troubling trend attributed to a combination of disease, parasitism, and unusual marine hazards such as jellyfish blooms (Knudsen, 2024).

Yet, it is crucial to acknowledge the heterogeneity in mortality rates observed across different farms and locations, even within identical production zones (Klakegg et al., 2023). This variation signals an opportunity for significant advancements in production methods, hinting at the unrealized potential for elevating welfare standards and reducing mortality through improved management planning and practices.

Sea lice remain at the forefront of industry-wide concerns, directly impacting both fish health and sector sustainability. The Institute of Marine Research identifies sea lice as one of the critical issues demanding effective and sustainable control strategies (Institute of Marine Research, 2018). Addressing such concerns is not only central to improving salmon welfare, but also pivotal to advancing the sustainability credentials of the entire industry.

Our thesis suggests that embracing new technologies like CCS and RAS, could present effective solutions to the longstanding challenges faced by the industry. However, the success of these technologies significantly depends on the specific post smolt strategy employed, as well as the cost framework and health conditions unique to each fish farming operation. Choosing the optimal strategy could potentially lead to a reduction in mortality rates by 40% and a decrease in sea lice treatments by 80%. By minimizing the environmental footprint and mitigating the factors that compromise fish health, these technologies could steer the sector toward an equilibrium of ecological responsibility and economic viability. Our research aims to critically evaluate how these technologies can redefine sustainability in the salmon industry, asserting that strategic shifts in farming operations could catalyze a transition to practices that are both sustainable and scalable. Our analysis also reveals that the inventory cost per fish in open nets, from initial stages through to harvest, varies significantly compared to illustrated post smolt strategies. These variations are influenced by the risk profiles associated with each generation, indicating diverse outcomes from the integration of post smolt strategies. It is crucial to identify, estimate, and understand these risk profiles across a range of smolt weights and the time of release into open net pens, before choosing RAS or CCS.

2.5 The Governmental Perspective on the Industry

Norway's Atlantic salmon aquaculture operates under strict licensing requirements set forth by the aquaculture law. This empowers authorities to regulate standing production volume, site selection, and facility design to mitigate disease spread, ensure fish welfare, and safeguard marine environments. The aquaculture permit, issued by the Ministry of Trade, Industry, and Fisheries, grants companies the exclusive right to operate on distinct locations along the public coastline, contingent upon adherence to governmental regulations and a commitment to contributing to local and national economic value (Directorate of Fisheries, n.d.). Each site permit is limited in a site-specific maximum allowed biomass (MAB), meaning that the holder cannot exceed the permitted MAB with their standing biomass (number of kilograms of live fish in seawater) at any point. The MAB permitted for a company varies based on the production region where its license is held. These company-owned MAB is defined as 780 MT of live biomass for southern Norway, whereas in the Troms/Finnmark region, such MAB is 940 MT at any time. MAB serves as an important metric in our evaluation, guiding our examination of which post smolt strategies exhibit more or less the optimal company-owned MAB permits in a region, its productivity across the annual cycle, and per post smolt strategy.

Introduced in 2017, the Traffic Light System classifies salmon farming licenses within 13 designated regions as ”green”, ”yellow,” or ”red,” based on the projected impact of salmon lice on wild salmon populations. This approach underscores the government’s commitment to balancing regional growth linked with environmental sustainability. The ”green” status may allow for increased production, with up to 6% expansion in the company-based regional MAB permits, while the ”red” status indicates an unacceptable impact on the wild salmon population, leading to production capacity reduction. Currently, only salmon lice levels determine the colour designation, but there is a move toward incorporating additional indicators like fish welfare and mortality, as highlighted in PwC’s 2023 Seafood Barometer survey (PwC Seafood Barometer, 2023). As of March 2024, the new colour designations for the 13x production regions have been released. In Western Norway, the production areas P2 and P5 got ”yellow”; meanwhile, P3 and P4 got ”red” for the third time (Nygård, 2024).

The recent evaluation of the Traffic Light System presented in 2021 by the Aquaculture committee reflects a governmental shift toward fostering technological innovation and sustainable industry expansion. The committee’s recommendations for minimizing environmental impact through advanced production systems mark a significant step toward enhancing fish welfare and worker safety (NOU 2023:23, 2023, p.55-113). Before the release into traditional open pens, the committee advocates for a strategic shift towards cultivating post smolt in controlled environments, such as on land or within CCS. This recommendation aims to mitigate environmental impacts and enhance fish welfare. Yet, the report stops short of offering specific, actionable recommendations, leaving a gap between it is strategic vision and the practical implementation of these proposed changes.

Moreover, the National Audit Office's 2023 report highlights pressing issues within the sector, including the presence of disease and high mortality rates, underlining the necessity for immediate, coordinated reform to address these challenges (Dokument3:12(2022-2023), 2022). It articulates a consensus among governmental bodies on the imperative for reforms to secure the industry's sustainable growth.

Our thesis positions itself within this critical dialogue, proposing that a shift towards innovative aquaculture technologies - namely CCS and RAS - could significantly address the government's and the industry's sustainability objectives. By examining the effectiveness of these systems in reducing mortality rates and environmental impact, our research offers practical analytic methodology and solutions to the challenges identified by governmental bodies, the public sector, and the media, contributing to the discussion on sustainable aquaculture practices in Norway.

3 Exploring Optimal Post Smolt Strategies through Simulation Modeling

3.1 Introduction

This segment of our thesis details the methodology that has enabled us to conduct a groundbreaking investigation into post smolt strategies within Norwegian salmon aquaculture. Central to our investigation is a unique dataset, compiled through collaboration with Ovum AS and the biologist Knut Senstad. This collaboration has not only given robustness to our findings but has also ensured access to insights previously not explored by the academic and industrial communities alike.

Our methodological framework is distinguished by its holistic approach, carefully blending quantitative precision with qualitative depth. The cornerstone of our quantitative analysis is a collection of industry trends, market dynamics, and operational metrics sourced directly from Norwegian salmon enterprises, authoritative institutional reports, and Knut Senstad's real-world experiences. This unique dataset is enhanced by detailed information from focused discussions and expert consultations, aimed at deepening our understanding of the aquaculture landscape.

Central to our methodological innovation is the use of advanced simulation modelling. This tool is meticulously calibrated to process each data input, cost factor (both fixed and variable), and operational detail with unparalleled precision and a fact-based approach. This model also stands as the base of our sensitivity analysis, revealing the potential variances in key performance indicators - cost efficiency, productivity, and sustainability - across different post smolt strategies. By integrating CCS and RAS with conventional open-net platforms, we disclose strategic insights that aim to redefine industry benchmarks and sustainability practices. In our analysis, we model nine distinct post smolt generations released in spring, each with correlated defined survival and growth potential. However, it is important to note that these parameters can vary significantly based on individual farming company practices, location, or due to cost influences.

3.2 Data Foundation

3.2.1 Methodology

3.2.1.1 Industry Data

Embarking on examining nine generations of post smolt released along the West Coast of Norway, we constructed a foundational dataset. Leveraging full-scale reports and analyses from the Directorate of Fisheries, we were able to clarify a detailed view of salmon production costs and profitability metrics that serve as a benchmark for our data. Additionally, we consulted industry experts to estimate conditions for the year 2024, in which our hypothetical post smolts are released in open net pens. Up-to-date industry cost elements, including full new feed cost from smolt to harvest, linked to the unit cost of different post smolts weights and precise market prices for harvested salmon for the year 2024, are included.

A central aspect of our data foundation is the partnership with Ovum AS and the engagement with the innovative EGG concept - a fully enclosed aquaculture globe characterized by its efficient water supply and waste management system. This collaboration provided us with reported unique biological and economic outcomes from two pilots of 1000 gram post smolt EGG generations. These findings, coupled with detailed cost analysis across all relevant variables and fixed cost elements, laid the groundwork for projecting the costs for varying post smolt sizes from the EGG system. An expanded version of the initial pilot EGG size has been implemented for the greater amount of post smolt farmed (1 million smolt) in this thesis. The CAPEX and OPEX for such large-scale commercial operations are fully accounted for in the post smolt unit costs outlined in our analysis. The biological and economic results from these generations are used to predict the cost of the EGG post smolt sizes of 200-, 400-, 600- and 800 grams. The EGG cohorts have been "farmed" inside the EGG platform, with its true cost and biological performances as experienced by Ovum AS, until the 1st of April, which is the day of release into open-net pens. Costs are based on all relevant variable and fixed cost elements, including depreciation of the EGG platform. Our illustrated 4x 1 million post smolt generation has incorporated Ovum AS new, larger commercial EGG shape, forming an enclosed structure of 20,000 m3. Escalated labour, energy (kwh), and oxygen costs linked to impressive growth and survival performance are included. Ovum AS achieved a consistent low eFCR (economical feed conversion ratio) and high survival rate, indicating efficient feed utilization and cost-effectiveness. By integrating these data, we've gained a greater understanding of the economic implications and possibilities of ongoing CCS initiatives, enabling us to draw actionable conclusions. A similar exercise could have been conducted with another CCS manufacturer; however, the limited data access and the scope of this master's thesis necessitated a narrower focus.

The unit costs for both the EGG post smolt and the RAS post smolt are thoroughly calculated. As for the EGG, the unit cost is calculated by simulating the 4x generations, providing us with the correct cost of the post smolt. The unit cost for each of the listed 4x RAS post smolt generations is obtained by addressing the latest published market price where the life cost per RAS post smolt is given a value of NOK 7.00 (a life cost; egg and vaccine costs) plus a biomass factor of NOK 0.09 per 1 gram fish weight. We stress the fact that the RAS post smolt is a market price excluding freight, whereas our EGG post smolt is a unit production cost excluding any reasonable margins and finance costs.

3.2.1.2 Model Input Data Analysis

The Fish Farming Economics Model (FFE), developed by biologist Knut Senstad, is an essential tool in our analysis. The model, including a dedicated post smolt section, transforms Senstad's industry experience into a comprehensive economic analysis tool. Senstad's extensive experience in Norwegian aquaculture has led to the creation of this comprehensive model, providing detailed insights into the economics of fish farming where also disruptive health conditions, biomass and cost implications are covered. It effectively incorporates CAPEX and OPEX data across traditional open net pens, RAS platforms, and the pioneering EGG concept, facilitating a robust economic evaluation of fish farming operations. Efforts have been made to portray realistic growth, survival, and costs for our baseline generation of 100 grams and the subsequent 8x post smolt generations, ensuring accurate outputs for the year 2024.

Our analytical approach carefully examines the growth and cost allocation of post smolt across eight distinct generations until harvest of 5.0 kg is reached. A critical component of our input data encompassed the fixed costs associated with various production methods. The model has incorporated the fixed costs from the open net pens into the output data in the different generations. While most generations share identical annual open net fixed costs, there's a notable exception for the 800 gram post smolts delivered from both RAS and the EGG. This larger post smolt size eliminates the necessity for the normal small mesh net pens traditionally required for smaller smolt.

Start Up and Depreciation Costs

In the input model, we detailed the startup costs for each of the 9x generation's production, such as operational expenses, which incorporate site preparation and labour costs spanning a minimum of two months before each smolt release, a phase known as the fallow period. Typical start-up costs include the depreciation cost of the CAPEX for the unused period from the last generation harvested in the open net assets, such as feed barges, service boats, moorings, land bases, and other production-related aspects. These expenditures are systematically depreciated over specified farming periods that align with the release of each generation into the open net cages. This ensures that the costs accurately reflect the lifecycle of the assets and are fully allocated to each of the biomasses being produced. Additionally, our financial analysis also accounts for the labour costs associated with site preparation for each new generation. The estimated aggregate CAPEX for marine and land-based assets associated with the open net strategy, 1 million smolt generation, is approximately MNOK 92. Of this investment, a sum of MNOK 41 is allocated for a full depreciation over a seven-year period, while the remaining MNOK 51 CAPEX and it is depreciation is spread evenly over fifteen years (Appendix, Table 4 and Table 5). This depreciation strategy is uniformly applied across all nine generations in our study. However, an exception is made for the two generations of 800 gram post smolts, which are subject to a slightly modified depreciation scheme due to their differentiated fishnet requirements.

This results in an annual depreciation cost for 7x of the generation of nearly MNOK 9.3, equating to approximately NOK 2.20 per kilo live at harvest per fish, which is representative for post smolts ranging from 100-600 grams. As for the 800 gram post smolt from RAS and EGG the total open net CAPEX is MNOK 89.5. Further, we calculated that around MNOK 5.8 annual depreciation was reflected in 7 years, and MNOK 3.2 annual depreciation was reflected in 15 years of depreciation. This provided a total annual depreciation of close to MNOK 9.1 for these larger post smolt sizes (Appendix, Table 6 and Table 7). We have also factored in additional OPEX cost components for the corresponding larger post smolt strategies.

General Input Parameters

Our analysis continues with the release of nine modelled post smolt generations into open nets by April 1st, aiming for a harvest live swimming weight of 5 kg. All open net generations consist of 8x large 158-meter circular cages with nets, feed barge, mooring, and site boats (Appendix, Input 1). Utilizing an "output" model, we navigate through various parameters, including startup costs, variable expenses, harvesting logistics, sales forecasts, temperature impacts, and treatment-related costs and losses. For generations with mechanical sea lice treatment, a slight quality downgrading factor is implemented. We've aligned our projections with 2022 data from the Directorate of Fisheries, enhancing our research reliability (Norwegian Directorate of Fisheries, 2024).

Each generation's growth course is calibrated daily, adhering to standardized growth tables that accommodate temperature variations from 6 to 17 degrees Celsius in the water. This ensures each generation achieves it is full growth potential of 100%. Our analysis ensures that RAS and CCS post smolt, with the same starting weight, i.e. 400 grams, exhibit identical growth patterns and time spent in nets. These groups are modelled to experience the same duration of sea farming, similar mortality rates, and undergo equivalent sea lice treatment protocols, leading to comparable weekly operational costs and biomass capability (Appendix, Input 4). Despite these similarities, a notable distinction emerges for the live cost per fish in the initial inventory for the different production methods (Table 6). This difference extends throughout the farming period, culminating in distinct inventory costs per fish and per kg fish by the time of harvest. At harvest, the cost of live swimming and the gutted cost in box will show deviations. This variation affects the overall mortality cost despite both strategies exhibiting similar percentage levels of individual fish loss. It's important to note that the feed conversion ratios - the biological (bFCR) - are consistent across all post smolt weight classes. This uniformity ensures that our comparative analysis of RAS and EGG strategies is grounded on comparable growth efficiency metrics.

Harvest Quality

In forecasting market dynamics, we consulted Søren Martens, CEO of Fishpool AS, anchoring our sales parameters to an anticipated market price of NOK 100 per kilo gutted in box for 2024. Additionally, we predicted a harvest quality grade before the negative impact caused by sea lice treatment as 93% superior grade of the total harvested biomass, 5% ordinary grade, and 2% production grade for all the 9x smolt strategies. However, as the generations experience different needs of sea lice treatments, there is a 1% increase in production-grade for each treatment required, affecting the overall quality grade distribution. This increased production grade makes the superior proportion of biomass harvested 1% less for each required treatment. Further, a generation with, i.e. 4x sea lice treatment has a superior grade reduced by 4%, whereas it is production-grade quantity is increased by 4%. For a more detailed breakdown of the costs associated with each production method and their respective justifications, please refer to Appendix and the input parameters (Appendix, Input 1).

Sea Lice Treatments

Our thesis highlights the adoption of advanced mechanical sea lice treatment methods. Our analysis is based on a standard performance metric, considering the entire treatment cycle - from the preparatory fasting of the generation before the treatment, through the treatment day itself, to the recovery period. This period is here characterized by an average of five additional days of reduced feeding, culminating in a total of seven days of operational disruption per treatment. Our model consistently applies an estimated 1% loss of fish across all smolt strategies at the date of sea lice treatment due to the treatment, ensuring a uniform assessment of treatment impact.

For larger post smolt generations, our model predicts a reduced frequency of sea lice treatments, reflecting strategic adjustments based on the season and the fish's weight. This nuanced approach is detailed in Table 3 in the Appendix, showcasing our effort to balance these critical factors throughout our analysis. Notably, each benchmarked post smolt weight category - taking the 400-gram generation from RAS and EGG as an example - incurs identical periods of starving days, treatment losses, lost feeding days, and associated treatment costs per generation, irrespective of its origin.

The comprehensive cost of a single mechanical treatment cycle per generation is approximately MNOK 1. This estimate, while slightly higher for smaller fish (under 2 kg), is considered more accurate for mid-range fish sizes and somewhat lower for those nearing harvest weight. These costs include about NOK 200,000 for each 24-hour, including external vessel and crew, supplemented by NOK 50,000 for a supporting smaller vessel and crew. Additionally, logistical considerations such as shipment to and from the site, along with cleaning, disinfection, and mandatory quarantine periods for the treatment vessel, have been factored into our cost analysis, ensuring a comprehensive understanding of the financial implications of sea lice treatment across different post smolt strategies.

Employing the FFE model with a cost allocation principle, we distribute all weekly incurred expenses to the remaining livestock, encapsulating operational and fixed costs. This ensures that the surviving fish bear the costs of any losses, including standard mortality rates. Variable costs such as depreciation, labour, and feed, as well as fixed costs, are fully accounted for upon harvest by the surviving livestock. Conducting this weekly ensures that accurate, fact-based loss costs are consistently applied to the surviving stock each week.

In our analysis, the operating margin, or EBIT, is calculated by evaluating both the inputs and outputs within our model. We derive EBIT across various post smolt strategies, leveraging an extensive dataset that captures the weekly nuances of fish cultivation. This dataset forms the basis for our comparative analysis of production methods, examined annually and across generations. Our forthcoming findings will delve deeper into this, showing the efficiency and profitability of each strategy. In calculating EBIT, we employ a specific industrial conversion factor for processing live swimming salmon - accounting for fasting, bleeding, and gutting processes - based on standards set by the Norwegian Directorate of Fisheries (Norwegian Directorate of Fisheries, 2024). This approach ensures that our financial assessments reflect the national real-world standards and costs associated with salmon farming, providing a solid foundation for evaluating the economic viability of different post smolt strategies.

3.2.2 Assumptions and limitations

Our thesis carefully examines one generation of fish at a time, a simplification compared to the complex reality. In the real world, fish farmers simultaneously raise multiple generations of varying sizes across different sites, exploiting their company's MAB permits within a region - all within the same calendar year. Our approach may not capture the full operational complexity of salmon farming, where the ongoing cycle of new generations and different fish sizes introduces additional layers of complexity to the analysis of each 12-month period. To ensure clarity and obtain definitive results from our simulation modelling, we have chosen to concentrate on analyzing a single spring generation at a time.

Our analysis also acknowledges potential limitations in capturing seasonal variations over a five-year span. We base our simulation on post smolts released on April 1st, with the correlating growth rates with prevailing water temperatures. In projecting these data over five years, we have applied consistent and repeated growth and survival rates derived from each of our four post smolts and the initial benchmark generations. However, these metrics may not precisely align with the actual growth rates and conditions for fish released in different seasons, such as midsummer or late autumn.

Additionally, we do not account for the initial costs of acquiring and developing RAS and the CCS EGG. However, all EGG post smolts have their true depreciation cost allocated to the illustrated EGG post smolt at release date. This decision stems from our focus on the operational dynamics and efficiency of the marine farming permit MAB regime rather than the capital expenditure on infrastructure. Given the diversity of RAS and CCS options, farmers must evaluate and select the best solutions according to their local requirements. By focusing on operational costs and performance metrics, we provide an analysis centred on system functionality and productivity, leaving out the complexities of initial investment considerations. We have also excluded financial and administrative costs from our EBIT calculations because these expenses can vary significantly between companies, making it difficult to achieve a fair and consistent comparison.

Lastly, introducing post smolts into open net pens represents a relatively new practice in salmon farming, leading to a shortage of research on the robustness and mortality rates of variously sized post smolts upon release. Despite this, we have based our analysis on carefully considered and reasonable assumptions, laying the groundwork for a well-founded and justified study.

3.3 Findings

Our objective is to identify which post smolt strategies deliver the most favourable outcomes and pinpoint any strategies that fall short under the operational conditions specific to the Western Norway region. We will begin with an overview of our key findings, including time spent at sea, mortality rates, and sea lice treatment across the different generations. This will be followed by a deeper examination of productivity and profitability, alongside an analysis of MAB utilization for each generation. Our goal is to evaluate the overall effectiveness of each post smolt strategy, focusing on factors such as fish welfare, sustainability, productivity, and operational margin per kg of harvest. Special emphasis is given to the number of MAB requirements for each strategy up to the point of harvest, where the same KPIs, such as welfare, sustainability, productivity, and operational margins, are illustrated.

3.3.1 General Findings

3.3.1.1 Generation Weeks in Open Nets

A critical aspect of our findings centres on the duration each generation spends in open sea nets. This metric is crucial for distinguishing the benchmark generation of 100 gram fish from subsequent generations originating from RAS and EGG, which feature progressively larger post smolt sizes. As these post smolts advance toward the target harvest weight of 5 kg, the time required in open nets varies significantly. Notably, generations with reduced sea durations - thanks to larger initial post smolt sizes - have the potential, over five years, to increase production with two additional generations. This is despite having consistent fixed costs, such as labour and depreciation, across this period (Table 1).

Table 1: Generation Details*

Generation	# weeks in sea	# generations in sea during 5 years
100g Benchmark	70	3.71
RAS 200g	64	4.06
RAS 400g	56	4.64
RAS 600g	47	5.53
RAS 800g	41	6.34
EGG 200g	64	4.06
EGG 400g	56	4.64
EGG 600g	47	5.53
EGG 800g	41	6.34

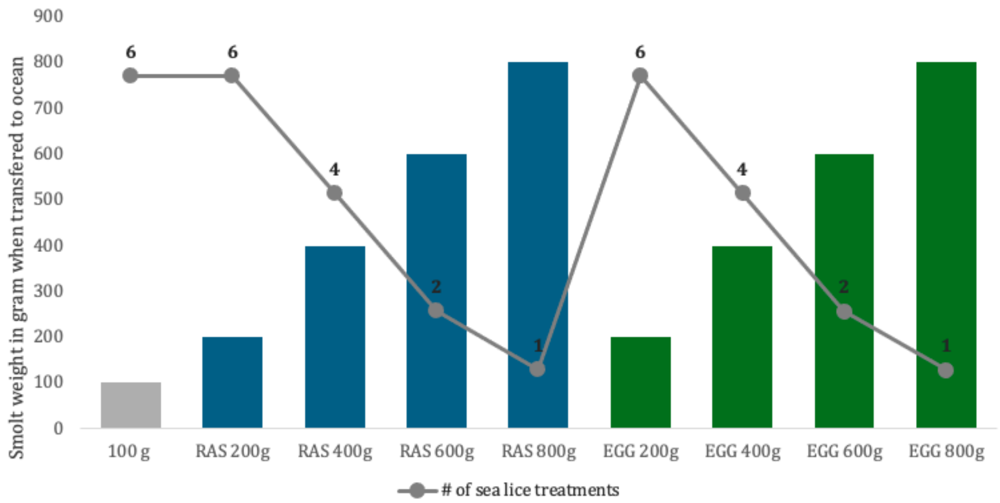
*Generations of the different post smolt strategies, how many weeks they spent in open net pens, and how many generations they could produce over a 5-year period.

Our study highlights that post smolts ranging from 200 to 800 grams from RAS undergo similar durations at sea as the corresponding weight classes from EGG. This uniformity is due to the current lack of detailed research into their growth potential, or as commonly referred to, their "robustness". Remarkably, the 800 gram post smolts benefit from a reduced sea tenure by 29 weeks. This shorter period potentially shields them from disease exposure and environmental hazards like algae blooms and jellyfish invasions, notably bypassing a second winter at sea. In contrast, the benchmark 100 gram generation faces 70 weeks in open net pens (Table 1), making them more vulnerable to multiple sea lice treatments and the rigors of two winter periods. Such extended exposure significantly escalates the risk of health complications and stress, contributing to the region's reported losses. Reducing sea duration, as demonstrated by larger post smolts, can substantially reduce these risks, bolstering fish health and resilience. Our subsequent analysis will explore how these variations in sea time distinctly affect the health outcomes of different generations.

3.3.1.2 Sea Lice Treatment and Mortality

The reduced sea duration for post smolt generations naturally leads to sea lice treatment frequency adjustments. For instance, the benchmark 100 gram generation and the 200 gram generation from both the RAS and EGG undergo six treatments. Yet, this number markedly decreases - to four, two, and one treatments - for the 400, 600, and 800 gram generations, respectively. To date, no research differentiates between the RAS and EGG origins in terms of their sea lice treatment needs under similar conditions, hence we view this as the same (Figure 2).

Figure 2: Number of Sea Lice Treatments Needed for Harvested Fish from each Generation



The influence of sea lice treatment on mortality is significant, affecting the overall mortality rates and associated costs. We observe a notable decrease in total mortality rates from 14.6% for the 200 gram generation to 9.4% for the 800 gram generation (Figure 3). Furthermore, the reduction in biomass loss due to treatments, as a percentage of total live biomass at harvest, shifts from 1.56% for the 200 gram generation down to 1.37% for the 800 gram generation. These findings underscore the opportunity for operational optimizations within aquaculture, aiming to enhance both the sustainability and efficiency of fish farming practices. Table 2 shows that the basis mortality and treatment mortality drastically decrease as post smolt sizes increase, which emphasizes the potential benefits of initiating a new post smolt strategy. Baseline mortality is all losses, excluding treatment loss.

Figure 3: Baseline Mortality in % in the Ocean Phase for the 9 Generations

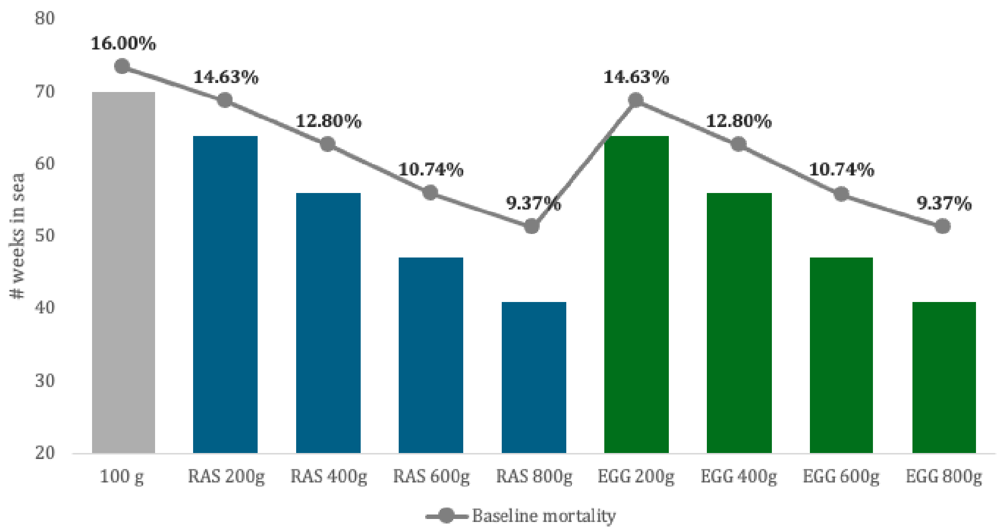


Table 2: Number of Basis Mortality and Treatment Mortality per Generation*

Generation	**# baseline mortality**	**# treatment mortality**	**# total mortality**	**Dead biomass as % of live harvest biomass**
100g	160,020	51,919	211,939	11.77%
RAS 200g	145,600	51,952	197,592	12.66%
RAS 400g	128,128	35,451	163,579	10.90%
RAS 600g	107,395	18,285	125,680	7.86%
RAS 800g	94,382	9,309	103,691	6.20%
EGG 200g	145,600	51,952	197,592	12.66%
EGG 400g	128,128	35,451	163,579	10.90%
EGG 600g	107,395	18,285	125,680	7.86%
EGG 800g	94,382	9,309	103,691	6.20%

*Baseline mortality per generation reflects overall mortality, excluding treatment-related deaths, while treatment mortality per generation indicates the number of fish dying from sea lice treatment. Total mortality combines baseline and treatment mortality per generation. Dead biomass as a percentage of live biomass represents the share of live biomass that dies per generation.

A fundamental finding of our analysis is that larger smolt sizes at the point of transfer to open net pens significantly reduce the frequency of sea lice treatments and the overall mortality rates. Notably, the proportion of dead biomass relative to live biomass at harvest decreases generation by generation, from 11.77% for the benchmark generation to 6.20% for the largest post smolt sizes

(Table 2). This decline underscores the benefits of extending the post smolt rearing period, highlighting a key strategy for enhancing aquaculture sustainability.

The financial implications of this reduction in mortality are significant, particularly in terms of the cost and value of mortality per surviving kilogram of live biomass at harvest date. For the benchmark generation at 100 gram, this cost stands at NOK 6.18/kg live at harvest. However, for RAS post smolt, this cost decreases to NOK 3.61/kg (800 gram), marking a significant leap in profitability. The EGG post smolt shows an even more substantial reduction, with costs dropping from NOK 6.23/kg (200 gram) at harvest to NOK 2.60/kg (800 gram) (Table 3). These figures represent the total mortality cost, which combines the baseline biomass loss costs with the costs associated with treatment-induced biomass loss. Notably, the NOK 6.18 mortality cost per kilogram of live salmon for the 100 gram strategy emerges as a major cost component, second only to the feed cost per kg of live salmon (Table 6). This finding invites a deeper investigation into how operational strategies and post smolt sizes influence the economic dynamics of salmon farming.

Table 3: Total Mortality Cost*

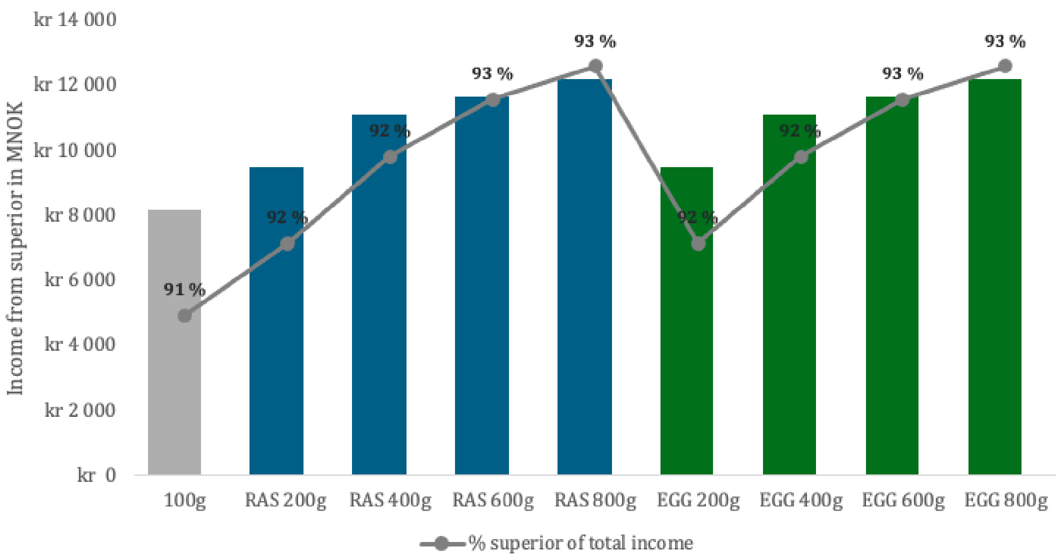
Generation	**Total mort. cost (NOK/kg) biomass harvested**	**Total cost of mortality per generation in MNOK**
100g	6.18	25.51
RAS 200g	6.42	25.89
RAS 400g	5.60	23.76
RAS 600g	4.28	18.71
RAS 800g	3.61	16.39
EGG 200g	6.23	25.14
EGG 400g	4.95	21.00
EGG 600g	3.43	15.01
EGG 800g	2.60	11.75

*Total mortality costs (NOK/kg) of live weight biomass harvested per generation indicate the cost burden per kg harvested. The total cost of mortality per generation (MNOK) represents the overall financial impact of mortality.

3.3.1.3 Harvested Live Weight/Harvested Quality

When the fish achieve the target live weight of 5 kg, they are harvested, undergoing automated processes of gutting, cleaning, and washing in preparation for quality assessment. Experienced staff then sort them into the three categories: superior, ordinary, and production grades (detailed criteria in Appendix, Input 1). The following table illustrates the revenue implications for superior-grade salmon across different post smolt weights, from 200 to 800 grams, sourced from both RAS and EGG technologies (Figure 4).

Figure 4: Superior Harvest Revenue in NOK per Year as % of income



The revenue implications of the harvested biomass is influenced by the proportion of the superior-grade commanding a market price of NOK 100.00. Ordinary-graded harvest is priced at NOK 98.50/kg gutted in box, whereas the production-grade has a market price set at NOK 80.00/kg. The prices are retrieved from Søren Martens, CEO in Fishpool AS (retrieved 06.02.24). As prices for ordinary- and production-grades decline, it becomes crucial to increase the percentage of superior-graded biomass. This underscores the importance of minimizing the time post smolts spend in the sea, as shorter durations lead to higher-quality superior-grade fish (Figure 4). Across all generations, the percentage of superior-grade fish in total income consistently exceeds 90%.

Notably, the peak percentage of total income attributed to superior-grade fish occurs at 800 grams for both RAS and EGG, reaching 93.1%. This dynamic underscores the critical economic advantage of cultivating superior-grade fish, especially evident in the 800 gram generation, which aligns closely with the anticipated 2024 market price of NOK 100.00. This alignment suggests enhanced profitability for the harvest from the 800 gram post smolt, compared to the slightly lower market returns anticipated for the 200 gram generation. The weighted average market price achieved spans from NOK 99.33 for the 800 gram post smolts to NOK 98.33 for the 200 gram counterparts, showcasing the financial benefits of targeting higher post smolt weights for optimal market pricing and profitability (Table 4).

Table 4: Weighted Average Achieved Market Price NOK/HOG*

Generation	Avg. achieved market price NOK/kg HOG	Delta in % from benchmark
100g	98.33	Benchmark
RAS 200g	98.33	Equal benchmark
RAS 400g	98.73	0.41%
RAS 600g	99.13	0.81%
RAS 800g	99.33	1.02%
EGG 200g	98.33	Equal benchmark
EGG 400g	98.73	0.41%
EGG 600g	99.13	0.81%
EGG 800g	99.33	1.02%

*The average achieved market price is the total income per generation divided by the total biomass HOG in kg. Delta in % from the benchmark is the difference in the average achieved market price from the 100 gram smolt.

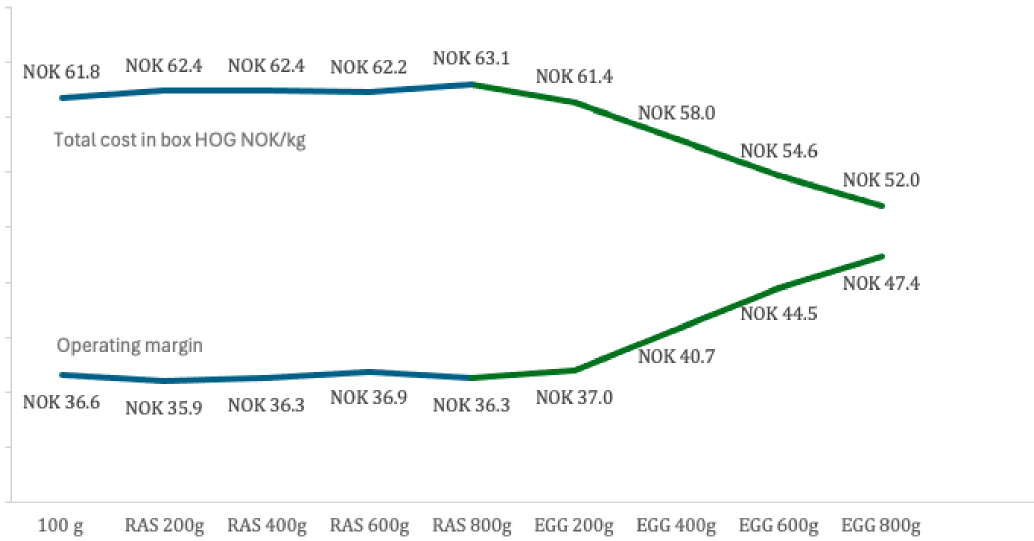
3.3.2 Profitability

Profitability and Operating Margin

Our analysis reveals that shorter sea durations, coupled with reduced sea lice treatments, lower mortality rates, and a higher ratio of superior-grade biomass, influence operational margins. Initially, the operating margin for the baseline

100 gram smolt is NOK 36.6/kg sold (Figure 5). However, the introduction of RAS and EGG technology introduces noticeable variations in these margins.

Figure 5: Operating Margin and Total Cost in box HOG NOK/kg



For post smolts utilizing RAS technology, the operating margin is anticipated to remain steady at around NOK 36/kg sold across all generations (Figure 5). This consistency is largely due to the initial smolt cost per RAS generation, which, when distributed over the harvested biomass, shows an increase of approximately 200% from the 200 gram to the 800 gram RAS generation. This increase negates the financial advantages typically associated with larger post smolt sizes. For instance, total smolt costs for the 100 gram benchmark generation amount to NOK 16.00 million (NOK 16,- per smolt). In comparison, RAS smolt costs span from NOK 25.00 million (NOK 25,- per smolt) to NOK 79.00 million (NOK 79,- per smolt), whereas EGG strategy costs range from NOK 21.56 million (NOK 21.56,- per smolt) to NOK 37.18 million (NOK 37.18,- per smolt) per harvested generation (Table 5). This underscores the importance of the original smolt cost on the operating margin per kg sold and how this influences the profitability of the different strategies (Senstad, 2022).

This pronounced difference is evident in the cost contribution per kilogram of live weight at harvest, which reveals a range from NOK 6.20 for 200 grams to

Table 5: Total Smolt Cost, Smolt Cost per kilo live at Harvest and Inventory Cost per kg Live at Harvest*

Generation	Total smolt cost MNOK	Total smolt cost per kg live at harvest	Avg. inventory cost live at harvest NOK/kg
100g	16.00	4.03	45.35
RAS 200g	25.00	6.20	45.88
RAS 400g	43.00	10.13	45.90
RAS 600g	61.00	13.95	45.75
RAS 800g	79.00	17.49	46.43
EGG 200g	21.56	5.34	45.03
EGG 400g	27.38	6.45	42.22
EGG 600g	33.18	7.59	39.39
EGG 800g	37.18	8.23	37.17

*Total smolt cost is the total costs of buying one million smolt/post smolt per generation, while total smolt cost per kg live at harvest divides the total smolt cost by the biomass harvested. Average inventory cost, live at harvest (NOK/kg), is the total production cost per generation divided by the correlating biomass harvested.

NOK 17.49 for 800 grams in the RAS, compared to NOK 5.34 for 200 grams up to NOK 8.23 for 800 grams in the EGG platform (Table 5). Notably, the cost increase is substantially lower for the EGG strategy than the RAS strategy. It is important to note that growth, survival, and operational costs are consistent across the respective weight classes for both RAS and EGG strategies.

Consequently, these variations significantly influence the average live inventory cost throughout the farming period, particularly at the time of harvest. The projected live weight cost at harvest is approximately NOK 45-46/kg for RAS, whereas it shows a reduction from NOK 45.03 to NOK 37.17/kg for the EGG strategy (Table 5). Therefore, EGG technology, which utilizes CCS, emerges as a more profitable option. This profitability escalates with the increase in post smolt weight under the EGG system, with the cost for a 800 gram EGG being NOK 8.18 lower per kilogram live at harvest compared to the 800 gram RAS. This finding underscores the significant economic benefits of various post smolt strategies, highlighting EGG as particularly advantageous. Table 6 provides a detailed breakdown of the average inventory costs at harvest for the benchmark generation, along with the 600 gram categories for both EGG and RAS technologies, comparing these figures to the 2022 results from the Directorate of Fisheries (Table 6). As the Directorate‘s figures are reported in whole fish equivalent (WFE) and our inventory costs are calculated based on harvested live weight, we have then applied their conversion rate of 1.067 to align these values (Norwegian Directorate of Fisheries, 2024). Additionally, it is important to note that the Directorate's figures do not account for full inflation or the increased feed costs of 2023, which may render these estimates lower than the actual costs. Remarkably, the cost estimates for RAS and EGG technologies are similar across all inventory costs, except for smolt costs. This particular cost is the most significant factor influencing the average inventory cost at harvest, resulting in substantially lower costs for the EGG technology than RAS. Table 6 showcases the significant differences between the traditional inventory costs reported by the Norwegian Directorate of Fisheries and our findings for the 600 gram RAS and EGG technologies.

Table 6: Inventory cost per kg live at harvest, whole fish equivalence (WFE) (NOK/kg)

Type*	**Fiskeri dir. 2022**	**100g live weight condition**	**100g converted to WFE**	**RAS 600g live weight condition**	**RAS 600g converted to WFE**	**EGG 600g live weight condition**	**EGG 600g converted to WFE**
Smolt cost	6.83	4.03	4.30	13.95	14.88	7.59	8.10
S & LC	4.03	5.11	5.45	3.56	3.80	3.56	3.80
Feed cost	23.17	26.22	27.98	22.59	24.11	22.59	24.11
Treatment cost	-	1.51	1.61	0.46	0.49	0.46	0.49
FOC	-	5.13	5.47	3.12	3.33	3.12	3.33
Insurancce cost	0.21	0.24	0.25	0.16	0.17	0.16	0.17
Disposal cost	-	0.24	0.25	0.16	0.17	0.16	0.17
Depreciation cost	2.78	3.14	3.35	1.91	2.04	1.91	2.04
OOC	12.20	-	-	-	-	-	-
AIC LaH	-	45.35	-	45.75	-	39.39	-
AIC WFEaH	49.22	-	48.38	-	48.82	-	42.03
%-change	BENCHMARK	-	-1.70%	-	-0.82%	-	-14.61%

*S & LC = Startup and Labour Cost, FOC = Fixed Operational Cost, OOC = Other Operating Costs, AIC LaH = Average Inventory Cost Live at Harvest, AIC WFEaH = Average Inventory Cost WFE at Harvest, %-change = Percentage Change from Benchmark

Biological Feed Conversion Ratio (bFCR) and Economic Feed Conversion Ratio (eFCR) are two key metrics that measure the efficiency with which fish convert feed into body mass. The bFCR represents the amount of feed required to gain one kilogram of body weight and is common for all generations when placed in open-net pens. At this stage in the production phase, it takes 1.20 kilograms of feed to produce one kilogram of live fish weight (Table 7). eFCR, on the other hand, takes only the surviving net biomass gain into account, where the feed cost for the produced gained dead biomass is also included. For instance, an eFCR of 1.36 for the 200 gram RAS generation implies a higher net economic cost compared to the 1.29 eFCR for the 800 gram RAS generation (Table 7). It is these subtle differences in the eFCR that may reflect the nuanced outcomes of the specific farming practices, feed types, and management strategies employed in each generation. Therefore, when assessing the viability of post smolt strategies, the eFCR is a critical economic indicator that complements the biological insights provided by the bFCR. In this section, it is particularly important to notice the difference between using "kilo live produced" and "kilo live harvested" when implementing a post smolt strategy. Benchmarking feed cost per kilo of fish harvested at this stage is not appropriate since the initial post smolt weight must be excluded. Employing kilo live produced as a metric ensures that the analysis focuses only on the feed conversion specific to the analysed phase, without the confounding effect of earlier growth stages.

Table 7: bFCR and eFCRp per kg Produced*

Generation	**bFCR**	**eFCR**
100g	1.20	1.34
RAS 200g	1.20	1.36
RAS 400g	1.20	1.34
RAS 600g	1.20	1.31
RAS 800g	1.20	1.29
EGG 200g	1.20	1.36
EGG 400g	1.20	1.34
EGG 600g	1.20	1.31
EGG 800g	1.20	1.29

*bFCR - Biological Feed Conversion Ratio: The amount of feed given to a generation divided by the total gained (produced) biomass at harvest. eFCR - Economic Feed Conversion Ratio: The amount of feed given to a generation divided by the net surviving live biomass gained (produced) at harvest.

Yield

Yield, defined as the ratio of the final harvested biomass to the initial number of smolts stocked, serves as a key indicator of production efficiency. Our analysis reveals that yield figures positively correlate with the initial weight of the post smolt. The benchmark generation resulted in a yield of 3.966 NOK/kg. This figure gradually ascends to a peak of 4.517 NOK/kg for strategies utilizing an initial post smolt weight of 800 grams, corresponding to both RAS and EGG technologies (Table 8). The observed yield increase from the benchmark to the 800 gram generation with approximately 14%, equating to a differential of 0.551 kg. This yield increase, combined with better margins and lower inventory costs at harvest, demonstrates the scalability and financial benefits of advanced post smolt strategies. Such strategies exemplify the operational and economic efficiencies achievable within the aquaculture sector by strategically adjusting smolt sizes.

In post smolt strategies, when farmers pay for additional smolt weight, they gain biomass effectively ”for free”. This means taht not all the yield is directly produced by the farmer at the point of harvest; a significant portion is contributed by the company operating the CCS or RAS platforms. Therefore, distinguishing between ”net kg produced yield per smolt” and ”kg harvest yield per smolt released” is essential. In this thesis, we are using ”net kg produced yield per smolt”.

Table 8: Yield

Generation	**Yield (NOK/kg)***
100g	3.966
RAS 200g	4.035
RAS 400g	4.245
RAS 600g	4.373
RAS 800g	4.517
EGG 200g	4.035
EGG 400g	4.245
EGG 600g	4.373
EGG 800g	4.517

*Yield (NOK/kg) is the biomass harvested divided by the number of smolt per generation.

3.3.3 MAB Analysis

3.3.3.1 MAB Regulations and Optimization

In the aquaculture industry, Maximum Allowed Biomass (MAB) is a regulatory ceiling limiting the total biomass a company can sustain within its operational parameters. This constraint is imposed at both company and individual site levels, ensuring that the biomass does not surpass the authorized MAB in designated regional zones. A standard permit for salmon farming in the west coast region typically sanctions an MAB of 780 metric tons (MT)(Directorate of Fisheries, n.d.). For entities possessing multiple permits, the aggregate MAB reflects the collective biomass of fish from successive cycles at any time within a defined region. It is also possible for the combined MAB across various sites within a defined region to exceed the total company MAB, occasionally leading to underutilized site-specific MAB allocations. This is very normal and reflects how the MAB regime in Norway is framed. Other foreign farming regions do not consider the company's MAB as we do in Norway, but focus on site-specific biomass MAB. The underlying aim within this framework is to maximize the net biomass yield from the company‘s total MAB allocations in a region, striving for optimization from both a biomass production standpoint and an economic viewpoint, all while adhering to sustainability benchmarks.

Site-specific MAB allocations can vary considerably and not always correspond linearly with the standard 780 MT per permit. Our analysis will utilize the conventional 780 MT benchmark as specified by the Directorate of Fisheries (Directorate of Fisheries, n.d.). Given similar growth rates, the MAB requirements for RAS and EGG smolt generations align in weekly needs, particularly from the 400 gram post smolt size onwards. These requirements proportionally increase as the cohort nears harvest. Other larger post smolt sizes require distinct MAB considerations that correlate with their steeper biomass increases and the illustrated shorter duration at sea.

The concept of MAB-year as a performance indicator for any post smolt strategies represents an alternative approach in aquaculture analysis, reflecting the variability in sea tenure and the dynamic fluctuations in biomass. This KPI accounts for mortality rates, seasonal influences, timing of smolt release, smolt weights, and the necessity of sea lice interventions. The MAB-year per generation is computed by aggregating the weekly total biomass kg live at sea and adjusting this total over a standardized annual cycle of 52 weeks. This yields a consistent metric for biomass productivity, facilitating comparative analyses and informed management of aquaculture operations, especially pertinent to post smolt strategies. Without such a benchmark KPI, it can be difficult for stakeholders to take adequate decisions for future farming strategies.

Among the 9x generations evaluated, each corresponds to a distinct MAB-year value, descending from 3.01 MAB-year until harvest for the benchmark reduced to 2.56 MAB-year until harvest for the two 800 gram generations (Table 9). This gradient reflects the strategic imperative of allocating MAB permits efficiently over time and according to the growth path of the biomass. The reduction in MAB-year for the 800-gram generation signifies a reduction of 0.45 MAB-years from the benchmark, translating into significant benefits in operational efficiency, productivity per MAB-year, risk mitigation and overall operational flexibility. The range of MAB-year productivity illustrated in Table 9 shows that the baseline generation achieves 1,312 MT live weight, while the 800 gram Postsmolt reaches 1,767 MT live weight, representing a +35% improvement in performance.

It should be noted, however, that the 200 and 400 gram post smolt strategies do not demonstrate a decrease in MAB-year relative to the benchmark (registering 3.17 and 3.22, respectively, against the benchmark of 3.01) (Table 9). These findings indicate that while larger post smolt sizes present clear advantages, intermediate sizes may not yield proportional efficiencies in MAB utilization.

This will certainly vary between companies within a region and also differ across other regions.

Table 9: MAB-Year

Generation	**Yearly MAB required per generation**	**Biomass kg live at harvest per generation**	**Biomass kg live harvest avg. yearly per company MAB-year**	**Number of generations during a 5-y period**
100g	3.01	3,966,004	1,312,248	3.71
RAS 200g	3.17	4,035,348	1,272,945	4.06
RAS 400g	3.22	4,244,591	1,319,605	4.64
RAS 600g	2.81	4,373,180	1,554,576	5.53
RAS 800g	2.56	4,517,320	1,767,502	6.34
EGG 200g	3.17	4,035,348	1,272,945	4.06
EGG 400g	3.22	4,244,591	1,319,605	4.64
EGG 600g	2.81	4,373,180	1,554,576	5.53
EGG 800g	2.56	4,517,320	1,767,502	6.34

*MAB - Maximum Allowed Biomass: The maximum permissible biomass living weight a fish farmer can have in the pen at any given time. MAB-year - Maximum Allowed Biomass per year: The MAB-year is computed by aggregating the weekly total biomass kg live at sea and adjusting this total over a standardized annual cycle of 52 weeks.

Over time, farming companies managing multiple MAB permits annually may have to adapt to new post smolt scenarios. These different strategies have various requirements on a company's MAB depending on generational turnover and harvested biomass. Historically, during the era spanning the 1990s to the 2010s, when standard practices involved raising smolts averaging 100 grams, the MAB-year metric was of lesser consequence. With the introduction of post smolt strategies, the importance of the MAB-year metric is increasing. This makes it essential to understand and prioritize it. The key to any post smolt strategy is to match the harvested biomass to the MAB-year for each specific aquaculture environment to optimize biomass productivity. This indicator has significant implications for cost assessments, revenue projections, and the calculation of EBIT on an annualized MAB basis. The conventional KPIs lose their potency, such as live cost per kilogram at harvest, cost in box/kg gutted or EBIT per kilogram. Being the lowest cost producer is no longer a guarantee of future market dominance; instead, the strategic optimization of the MAB-year may become the true, real key to competitive advantage.

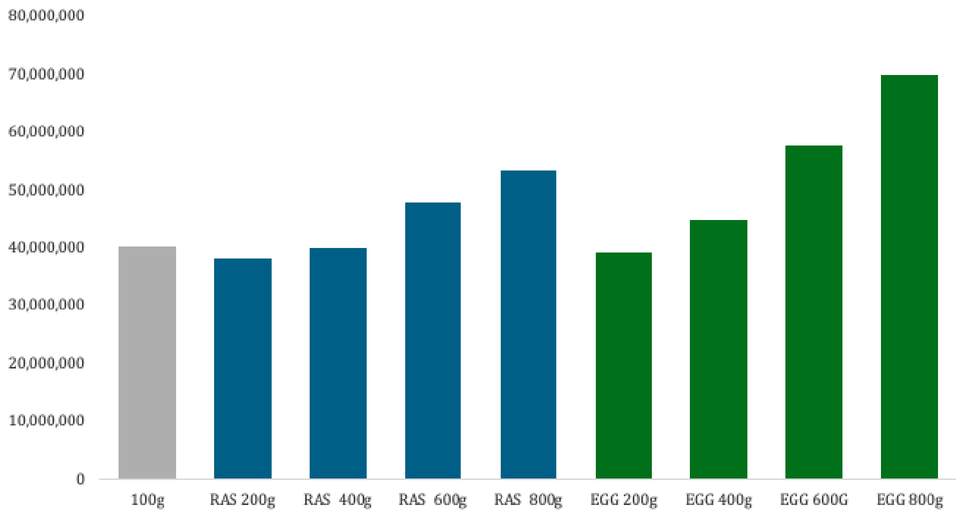
3.3.3.2 MAB Profitability

In evaluating the efficiency and effectiveness of various salmon farming strategies, adopting an overall perspective that extends beyond conventional financial metrics such as operating margin and cost per generation is crucial. Traditional indicators, while valuable, may not fully encapsulate the complexities and nuances of aquaculture productivity and profitability. Consequently, it becomes crucial to incorporate more advanced measures like profitability per MAB-year, which offer a detailed analysis of biomass harvested against regulatory constraints across generational strategies.

Looking into the cost in box HOG in NOK/kg, it is observed that the RAS strategy maintains a relatively consistent expenditure of approximately NOK 62.00 per kg across various generations. In contrast, the EGG systems demonstrate a marked reduction in costs, diminishing from NOK 61.40 to NOK 52.00 as the initial weight of post smolt increases (Figure 5). This decrease reflects greater financial efficiency as the weight threshold rises and should trigger a better facted based decision toward integrating such technology.

A detailed analysis of the EBIT per MAB-year, as shown in Figure 6, uncovers a consistent upward trend in financial returns correlating with the increasing weights of post smolts in both RAS and EGG approaches. Notably, the EGG system's 800 gram post smolts stand out, offering a substantial financial edge as high as 74% above the established benchmark. Comparatively, the 800 gram RAS post smolts also outpace the standard, albeit at a lower rate of 33%. This evidence emphasizes the strategic importance of optimizing MAB utilization, a key factor in industry licensing processes. It suggests stakeholders should develop strategies to enhance economic yield and sustainability by focusing on the MAB-year metric.

Figure 6: EBIT Operating Margin NOK excl Finance and Admin per MAB-year per Generation

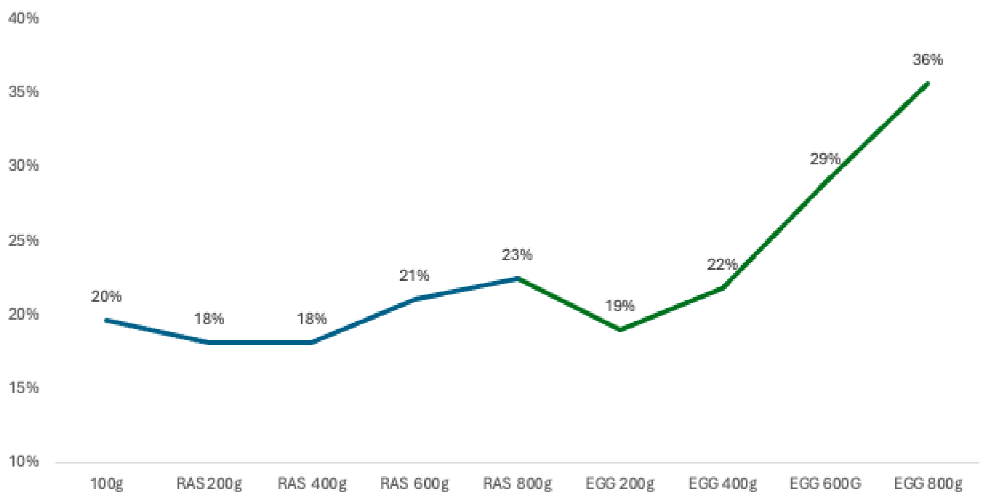


Looking further into the Return on Capital Employed (ROCE) in relation to EBIT provides additional insights. Initially, ROCE for both EGG and RAS strategies at the 200 gram benchmark is comparable. A notable difference arises as we look at the 800 gram generation, where RAS has an increase of 27% in ROCE (Figure 7). The EGG strategie, however, show a more significant, almost exponential enhancement in ROCE. The ROCE escalates from 19% to 36%, a leap signifying a 90% increase. This rise is primarily credited to the higher EBIT per MAB-year yielded by EGG strategies, which experiences a 73.90% rise over the benchmark, while the RAS counterpart records only a 33.20% increase. Such figures underscore the effectiveness of EGG's post smolt strategy in terms of capital allocation, generating considerable returns on investment as illustrated in Figure 7. Emphasizing these key performances could lead to a strategic shift in how post smolt sourcing strategies are created and used.

3.3.3.3 MAB Utilization

The MAB-year requirement and its evaluation as a KPI for post smolt strategies is a novel concept that has not been previously published to the best of our

Figure 7: ROCE in % per MAB year



knowledge. Kontali Analyse AS, a leading analytics firm within the seafood sector, is at the forefront of this innovation, setting a benchmark for the Norwegian salmon industry by measuring EBIT per standard MAB and evaluating MAB utilization across companies - a methodology unique to their reports.

Kontali Analyse AS's periodic reviews for the year 2022 provide an insightful look at MAB utilization, averaging figures from the industry's top quartile performers. "The utilization of the MAB is measured by the average harvest quantity per standard license over the last two years" (Kontali, 2022). These analyses reveal an average productivity of 1,181 tonnes of gutted weight per standard MAB license annually, an increase of 4% compared to the previous year. This translates to productive output of 1,417 tonnes of live-weight fish per MAB-year, considering a conversion ratio of 1.20, as demonstrated in Table 10. Recognizing that these numbers account for operational downtimes and transitions between generational cohorts is important. Kontali's aggregated data reflects diverse production locales, while our specific analysis renders detailed scenarios for phases P2-P5.

This analysis allows for a comparative evaluation of distinct post smolt generational strategies, particularly when contrasting the smaller 200 gram and 400 gram generations with their larger 600 gram and 800 gram counterparts.

Table 10: Yearly MAB Utilization on a Live Weight Basis*

Generation	**Productivity per MAB-year in live tonnes**	**Delta from benchmark**
Kontali 2022	1,417.20	Benchmark
100g	1,316	-7.1%
RAS 200g	1,273	-10.2%
RAS 400g	1,320	-6.9%
RAS 600g	1,555	9.7%
RAS 800g	1,768	24.7%
EGG 200g	1,273	-10.2%
EGG 400g	1,320	-6.9%
EGG 600g	1,555	9.7%
EGG 800g	1,768	24.7%

*The productivity per MAB-year is computed by dividing biomass harvested by the required yearly MAB. All generations are compared to the productivity per MAB-year given by Kontali Analyse AS (In this table referred to as the Benchmark) (Kontali, 2022)).

Kontali Analyse AS findings suggest that strategies incorporating post smolts of 600 gram or 800 gram from RAS or EGG are likely to be competitive when benchmarked against the leading entities within the industry. Specifically, the productivity per MAB-year for the 800 gram generation is projected to be 24.70% higher relative to Kontali's industrial average benchmark, indicative of an enhanced MAB utilization per existing permit, thereby optimizing the post smolt strategy (Table 10). The quantitative data underpinning our MAB utilization analysis has been furnished by Ragnar Nystøyl, Chief Analyst at Kontali Analyse AS, as of the 2nd of April, 2024.

3.3.4 Sensitivity Analysis

In evaluating the influence of variables on the efficiency and viability of post smolt strategies, sensitivity analysis emerges as an important tool. This analysis will specifically address the dynamic and potentially variable nature of mortality and growth rates over time, introducing uncertainty into model inputs (Saltelli et al., 2019). The scope of this sensitivity analysis encompasses the baseline generation of 100 gram post smolts and extends to the two 600 gram post smolt generations from both RAS and EGG. This stress testing aims to extract critical insights into the resilience and flexibility of each strategy when subjected to variable conditions.

Mortality and growth rates represent factors that substantially influence the outcomes of any salmon production platform, serving as fundamental determinants of success or setback. Given the assumptions made for both variables in our previous analysis, it is essential to stress test these parameters to check the robustness and reliability of our findings towards a best- and worst-case scenario (Table 11).

Table 11: Assumptions for Sensitivity Analysis*

Cases/Assumptions	**Mortality rate**	**Growth rate**
100g Worst	17.6%	95%
100g Base	16.0%	100%
100g Best	14.4%	105%
600g RAS/EGG Worst	9.1%	95%
600g RAS/EGG Base	10.7%	100%
600g RAS/EGG Best	11.3%	105%

*Assumptions for the sensitivity analysis on the mortality rate and the growth rate for the 100 gram, 600 gram RAS and 600 gram EGG generation.

To calculate the impact of these variables, we manipulate the daily growth potential to simulate both a 5% increase and decrease from the normative rates across all temperatures and biomass scales. Mortality rates are similarly tested, with adjustments to represent a 10% improvement and a 10% decline from baseline figures. These variations in growth and mortality are considered plausible for both benchmark, EGG and RAS strategies (Table 11).

In the context of the total cost in box HOG NOK/kg, the analysis reveals that the cost implications for the EGG 600 gram generation consistently remain below those projected for the RAS generation across all considered scenarios. Notably, the cost in box for the 600 gram EGG generation in the worst-case scenario at 56.7 NOK/kg is observed to be lower than the best-case scenario for the 600g RAS generation at 61.2 NOK/kg, which underscores the cost-effectiveness of the EGG system in the context of adverse conditions (Table 12).

This trend consistently extends to operating margins, where even under the most adverse conditions, the EGG generation sustains a favourable margin of 4.30 NOK/kg sold over the RAS approach. Moreover, when analyzing EBIT excluding finance and administrative costs per MTB year, the 600 gram EGG generation under worst-case conditions parallels the RAS baseline at about 47 million NOK - highlighting its resilience (Table 12). Despite this, the EBIT values for both RAS and EGG in their respective scenarios demonstrate superior financial outcomes compared to the highest EBIT achieved by the 100 gram benchmark generation.

Sensitivity analysis confirms the robustness of the 600 gram EGG generation's financial performance, resiliently withstanding suboptimal growth and mortality rates. These insights accentuate the EGG strategy's strategic superiority, affirming its robustness against the variable and challenging conditions characteristic of aquacultural practice.

MAB Findings in the Sensitivity Analysis

Analyzing the MAB utilization based on the sensitivity analysis presented in Table 12, illustrates that fluctuations in mortality and growth rates profoundly influence both the MAB-years required and the productivity per MAB-year for each generation (Table 13). The base- and best-case scenarios illustrated for the 600 gram generations from both RAS and EGG systems demonstrate superior performance compared to the 100-gram benchmark, with a reduced demand for MAB-years per generation by 16.9%. Furthermore, the productivity metrics for the 600 gram RAS and EGG generations for base- and best-case outperform the industry benchmark reported by Kontali Analyse AS, signifying the robustness and efficiency of the 600 gram post smolt strategy in the face of variable biological rates. This efficacy is further validated by the

Table 12: Key Findings from the Sensitivity Analysis*

Scenarios (cases)	Total cost in box HOG NOK/kg	Operating margin NOK/kg sold	EBIT (excl. finance and admin. cost) per MAB year in NOK	Delta change in EBIT per MAB per year in NOK
100g Worst	62.9	35.4	35,460,331	-11.78%
100g Base	61.8	36.6	40,196,505	Benchmark
100g Best	60.5	37.8	42,915,738	6.76%
600g RAS Worst	64.4	34.5	38,888,470	-3.25%
600g RAS Base	62.2	36.9	47,875,414	19.10%
600g RAS Best	61.2	37.9	56,567,727	40.73%
600g EGG Worst	56.7	42.2	47,616,489	18.46%
600g EGG Base	54.6	44.5	57,764,857	43.71%
600g EGG Best	53.7	45.4	67,773,899	68.61%

*Overview of the most significant results from the sensitivity analysis for all the different scenarios.

ROCE, where the base- and best-case scenarios of the EGG 600 gram generation achieve a superior ROCE compared to both the RAS generation and the 100 gram benchmark.The ROCE for the EGG technology showcases a worst-case scenario of 23.4%, still outperforming the 100 gram best case at 20.9% (Table 13). These findings describe the strategic financial and risk advantage of incorporating EGG technology as a source for the post smolt stage, highlighting its potential to elevate financial returns.

Table 13: MAB Utilization from the Sensitivity Analysis*

Scenarios (cases)	**MAB-year requirement per generation**	**Productivity, kg live, per MAB-year per generation**	**Delta change in productivity from Kontali**	**ROCE**
Kontali Analayse AS	-	1,417	Benchmark	-
100g Worst	3.28	1,199	-15.4%	-17.2%
100g Base	3.01	1,316	-7.1%	19.7%
100g Best	2.99	1,358	-4.2%	20.9%
600g RAS Worst	3.19	1,350	-4.7%	16.8%
600g RAS Base	2.81	1,555	9.7%	21.1%
600g RAS Best	2.48	1,758	26.0%	25.0%
600g EGG Worst	3.19	1,350	-4.7%	23.4%
600g EGG Base	2.81	1,555	9.7%	29.0%
600g EGG Best	2.48	1,758	26.0%	34.1%

*MAB-year: Maximum Allowed Biomass per year. Productivity per MAB-year per generation: the amount of live biomass produced per MAB-year. ROCE: Return on Capital Employed. The table compares the productivity and economic performance of the different post smolt strategies and scenarios, with data sourced from Kontali Analyse AS and the sensitivity analysis results.

The sensitivity analysis reveals key financial metrics under varying scenarios for the 600g RAS and EGG generations. The cost-effectiveness of the EGG system is notably consistent, maintaining a lower cost than the RAS across all scenarios. Regarding operating margins and EBIT, the 600g EGG also demonstrates resilience, outperforming the baseline 100g generation even under the worst-case scenario. These summarized findings highlight the superior financial resilience and very high productivity of post smolt by the EGG technology, making it a promising strategy within the aquaculture industry.

3.3.5 NPV Analysis

In the conclusion of our analysis, we have conducted a Net Present Value (NPV) analysis using the Discounted Cash Flow (DCF) model, comparing the outcomes of releasing 600 gram post smolt using both EGG and RAS systems against the benchmark strategy employing 100 gram smolt. Our estimations are based on the first year of post smolt release in open net pens. Assuming identical mortality rates and viability for post smolt in open net pens from both RAS and EGG, we utilized the same calculated weighted average cost of capital (WACC) for the two strategies. Compared to the benchmark, our calculations indicate a slightly reduced WACC for releasing 600 gram post smolt from either RAS or EGG. This reduction reflects the potentially lower risk and higher operational robustness of these methods. The strategic benefits, particularly the enhanced environmental sustainability associated with these methods, are expected to lead to reduced risk premiums demanded by investors, thus contributing to the lower WACC. We estimated the cost of debt using the 10-year swap rate (CBonds, n.d.) and calculated the cost of equity based on the risk-free rate from the 10-year government bond (Central Bank of Norway, n.d.), retrieved April 2nd 2024. We also factored in a market risk premium of 5% according to PwC (PwC, 2023) and used a levered equity beta of 0.62 for EGG and RAS systems, compared to 1.01 for the benchmark. To determine the unlevered beta, we utilized the average 5-year beta from peer groups and adjusted it specifically for EGG and RAS strategies. Our determined WACC stands at 8.2% for benchmark strategy and 7.3% for 600 gram RAS and EGG strategies (Table 14). This is consistent with research indicating that stakeholders typically assign a lower WACC to sustainable investments, recognizing their reduced risk profile (Mariani et al., 2021). We applied a 4% growth rate for all strategies, which we adjusted to 5% in year 5 for the RAS and EGG strategies. This reflects the impact of the cash flow effect where ESG activities positively impact the future cash flow (Richard Paul Gregory, 2022).

Table 14: NPV Across Generations*

Generation	FCF in NOK	TEV in millions NOK	WACC
100g	70,568,910	1,257	8.2%
RAS 600g	116,615,038	2,585	7.3%
EGG 600g	140,623,106	3,118	7.3%

* FCF: Free Cash Flow, a measure of the cash generated by the business after accounting for capital expenditures. TEV: Total Enterprise Value, the total value of a company, including debt and excluding cash. WACC: Weighted Average Cost of Capital, the average rate of return a company is expected to pay its shareholders for using their capital. The table compares the financial performance of different post smolt strategies across generations.

Our findings further emphasize the favourable nature of the post smolt strategy, particularly when employing EGG system. The NPV is significantly higher for both RAS and EGG compared to the benchmark, with a TEV of MNOK 2,585 for RAS and MNOK 3,118 for EGG, against MNOK 1,257 for the benchmark (Table 14). These figures suggest that investments in post smolts, particularly through EGG system, offer more advantageous economic opportunities and improved financial performance in the long run. The primary driver behind these results is the difference in FCF, where RAS and EGG present significantly higher figures than the benchmark. Furthermore, the divergence in WACC also amplifies the superior NPV outcomes for RAS and EGG. These findings highlight the compelling economic and strategic reason for investment in post smolt technologies, such as RAS and EGG, which, as well as mitigating risks, offer substantial financial upside and contribute positively to environmental sustainability goals.

Given fish farming operations' complex and dynamic nature, numerous variables can significantly impact the NPV results. By performing a sensitivity analysis, we can systematically assess how changes in key factors influence the financial viability of our investment. This provides insights into the robustness of our findings, allowing us to identify and understand potential risks and uncertainties associated with the project.

Figure 8: Sensitivity analysis for the benchmark, the 600g RAS and the 600g EGG generation

TEV in millions (100g)		WACC					
	kr 1257	5.00%	6.00%	7.00%	8.00%	9.00%	10.00%
Growth rate	1%	kr 2087	kr 1567	kr 1256	kr 1050	kr 902	kr 792
	2%	kr 2268	kr 1696	kr 1354	kr 1127	kr 965	kr 844
	3%	kr 2466	kr 1836	kr 1460	kr 1211	kr 1034	kr 901
	4%	kr 2680	kr 1988	kr 1575	kr 1301	kr 1107	kr 963
	5%	kr 2912	kr 2152	kr 1699	kr 1399	kr 1187	kr 1029
	6%	kr 3165	kr 2330	kr 1833	kr 1505	kr 1272	kr 1100

TEV in millions (600g RAS)		WACC					
	kr 2585	5.00%	6.00%	7.00%	8.00%	9.00%	10.00%
Growth rate	1%	kr 4307	kr 3189	kr 2522	kr 2081	kr 1768	kr 1535
	2%	kr 4430	kr 3278	kr 2591	kr 2137	kr 1815	kr 1575
	3%	kr 4555	kr 3369	kr 2662	kr 2194	kr 1863	kr 1616
	4%	kr 4683	kr 3462	kr 2734	kr 2253	kr 1911	kr 1658
	5%	kr 4813	kr 3556	kr 2808	kr 2312	kr 1961	kr 1700
	6%	kr 4945	kr 3652	kr 2882	kr 2373	kr 2012	kr 1743

TEV in millions (600g EGG)		WACC					
	kr 3118	5.00%	6.00%	7.00%	8.00%	9.00%	10.00%
Growth rate	1%	kr 5194	kr 3845	kr 3041	kr 2509	kr 2132	kr 1851
	2%	kr 5342	kr 3953	kr 3125	kr 2577	kr 2189	kr 1900
	3%	kr 5493	kr 4063	kr 3210	kr 2646	kr 2246	kr 1949
	4%	kr 5647	kr 4174	kr 3297	kr 2716	kr 2305	kr 1999
	5%	kr 5803	kr 4288	kr 3386	kr 2788	kr 2365	kr 2050
	6%	kr 5963	kr 4404	kr 3476	kr 2861	kr 2426	kr 2102

The sensitivity analysis of our NPV findings shows the varying impact of different WACC and growth rates on the TEV for the strategies (Figure 8). For the 600 gram EGG strategy, there is a clear decline in TEV as WACC increases, which is expected since higher discount rates reduce the present value of future cash flows. However, even at a WACC of 10%, the lowest TEV reported for the 600 gram EGG remains significantly higher than the benchmark's highest TEV. This demonstrates the robustness of the EGG strategy, even under higher WACC scenarios. The sensitivity to growth rates is also apparent; higher growth rates drastically increase the TEV, showcasing the upside potential for the EGG strategy. Similarly, the 600 gram RAS strategy outperforms the benchmark across all WACC and growth rate scenarios, though it generally yields a lower TEV than the EGG strategy. This indicates that while RAS is a sound investment, the EGG strategy might offer greater financial benefits. The benchmark strategy exhibits a TEV that is notably more sensitive to changes in WACC, with the TEV dropping below MNOK 1,100 at a 10% WACC, even at the highest growth rate. This suggests that the benchmark strategy is the most vulnerable to increases in the cost of capital and has a more limited upside than the 600 gram strategy. Overall, the sensitivity analysis confirms the resilience and financial superiority of the 600 gram post smolt strategies over the traditional benchmark.

4 Discussion

Our analysis reveals that developing post smolt to larger sizes before the release into open net pens under our defined conditions significantly enhances profitability compared to traditional practices of releasing 100 gram smolt. Implementing this approach shortens production cycles, leading to fewer sea lice treatments, decreased disease exposure, and increased operational flexibility. For example, the 800 gram post smolt generation typically spends 29 weeks less in the sea than the 100 gram baseline, requiring substantially fewer sea lice treatments - from six to just one. Over five years, this strategy potentially increases the number of generational cycles in the sea from 3.71 to 6.34, significantly boosting productivity and profitability over time. This approach could especially be beneficial in farming areas experiencing high mortality rates and stringent health regulations. However, other areas or specific sites within these challenged regions might still perform well without the need to integrate post smolt into open nets. The selection of the optimal post smolt strategy must be a careful decision influenced by multiple factors. These include the company's operational capabilities, specific environmental conditions of the sites, and, importantly, the strategic objectives the company aims to achieve. For instance, companies focusing on a need to improve their sustainability might favour technologies that offer better environmental controls regardless of cost or EBIT. The findings suggest optimal outcomes in environments where growth opportunities are maximized daily, and losses are consistently distributed throughout the lifespan of each generation.

Despite the prevalent use of RAS for post smolt operations, our findings highlight that the CCS, in this case the EGG technology, offers superior cost efficiency and operating margins, both per kg sold and also per MAB-year. The smolt cost is the most significant factor influencing the average inventory cost at harvest, resulting in substantially lower costs for the EGG technology than RAS (Table 6). This crucial cost split underscores how the lower cost smolt directly enhaces the overall economic advantage of the EGG system. Furthermore, our sensitivity and NPV analyses reaffirm the superiority of the EGG system, particularly in the context of the 600 gram generations, which served as the primary focus of our comparison. These findings provide valuable insights for informed decision-making and future strategic planning within the sector.

Both land-based RAS and CCS have faced challenging operational issues in the past. Land-based facilities have struggled with AGD parasites, the breakdown of the biofilters and H2S gas emissions. Similarly, CCS platforms have encountered issues such as metal corrosions in the marine environment, AGD parasites, degradation of metal collar structures, and damage to semi-enclosed PVC bags. Despite these challenges, CCS platforms can provide significant advantages, particularly when integrated with existing open-net systems that already utilize service boats and feed barges. Stakeholders should therefore weigh their options carefully, considering both operational goals and environmental responsibilities. We advocate for a synergistic approach that utilizes both systems to enhance fish welfare and sustainability - reducing losses, minimizing biomass mortality, improving eFCR, and enhancing operational margins. This strategy promises substantial benefits for all parties involved.

4.1 Which Post Smolt Strategy Should one Choose?

The choice of an appropriate post smolt strategy is critical to the operational and financial success of aquaculture enterprises, particularly highlighted by our analysis of the Western Norway region's farming operations. We have identified two clear takeaways: firstly, the integration of any post smolt strategy, notably in Western Norway with its conditions of today, has proven to be significantly profitable. Secondly, the CCS technology consistently might outperform the benchmarked RAS in terms of operational benefits.

While our analysis highlights the profitability and advantages of these technologies, it does not encompass the capital expenditures involved in establishing such facilities. For example, initiating a standard RAS facility to handle 3,000 MT post smolt of biomass annually is estimated to require an investment of approximately NOK 1.1 billion, resulting in a CAPEX of approximately NOK 350 per kg capacity. In contrast, setting up a CCS unit capable of accommodating a post smolt generation of 600 MT (one million fish of 600 gram) with a density of maximum 30 kg per 1,000 litres, comes with a significantly lower initial investment of around MNOK 100. Delivering three such post smolt generations per year (in sum 1,800 MT) may result in a CAPEX of NOK 56,- per kg capacity. This severe difference in initial investment highlights the necessity of a thorough financial analysis focusing not only on the upfront costs, but also on the long-term returns and operational expenses.

The superior outcomes demonstrated by the EGG post smolt strategy, coupled with its comparatively modest initial investment, underscore its cost-effectiveness and suggest a favorable outlook for long-term profitability. As such, stakeholders should consider both the immediate financial impact and the strategic benefits of potential scalability and reduced operational risks when choosing the most suitable post smolt strategy. This careful consideration will ensure alignment with the company's long-term goals and financial health, paving the way for a sustainable and profitable operation.

4.1.1 Recommended Strategy

In light of our analysis, we advocate for the adoption of a post smolt strategy that rears smolts ranging from 400 to 800 grams using the CCS technology, here illustrated by the EGG concept. This recommendation is grounded in robust findings from our research, which illustrate that the sustainability and profitability benefits of CCS significantly surpass those achievable with RAS. Notably, our results demonstrate that the advantages of employing a post smolt strategy become substantial at the 400 gram mark and escalate further as the weight approaches 800 grams.

Our study suggests that targeting post smolt sizes as low as 200 grams may not yield improved profitable or sustainable outcomes. Beyond the 400 gram threshold, tangible benefits seem to appear, with increasing advantages up to and possibly beyond 800 grams. These findings underscore the criticality of selecting optimal weight thresholds for post smolt growth to maximize the benefits of CCS technologies.

Although our research did not include a similar analysis across all potential generations using CCS technology, the data collected strongly supports the superiority of the CCS approach over RAS in terms of both environmental sustainability and economic viability. Therefore, even without a direct comparison, the evidence strongly supports implementing the CCS-based post smolt strategy. Moving forward, there is a promising direction for research into the benefits of different post smolts weighing over 800 grams. Exploring these possibilities could further enhance the effectiveness and applicability of post smolt strategies in the fish farming industry.

4.1.2 The Benefits of Implementing Post Smolt Strategy

The accompanying table highlights key benefits that validate our recommended post smolt strategy using CCS (Table 15). These metrics demonstrate significant advantages in operational efficiency, economic viability, and sustainability achieved through this approach.

The data reveals substantial improvements in the accumulated total cost related to lice and the percentage of dead fish relative to live kg harvested for the 600 gram strategies, reflecting improved fish health and survival rates. Moreover, the increase in harvested biomass indicates a higher yield and more efficient utilization of resources. Importantly, the economic metrics, particularly the EBIT in million NOK per MAB-year, demonstrate that both the EGG and RAS 600 gram methods significantly boost profitability. This economic metric highlights a robust increase, with the EBIT per MAB year exceeding the benchmark generation of 100 grams by more than 40% for the EGG technology, affirming the financial benefits of scaling post smolts to 600 grams prior to sea transfer. The cost efficiency of the EGG 600 gram strategy is also especially remarkable. Although both strategies offer substantial improvements over the 100 gram benchmark, the EGG technology features lower total costs per box per generation per MAB-year, highlighting its potential for even greater economic and operational efficiencies. This data solidly supports our recommendation to adopt the EGG strategy at a minimum of 400 grams, optimizing economic returns and enhancing sustainability in aquaculture practices.

Table 15: Sustainability Metrics*

Metrics per generation	100g	RAS 600g	EGG 600g
Number of weeks in sea	70	47	47
Number of sea lice treatments	6	2	2
Cost related to lice per kg live harvest	1.55	0.53	0.53
Acc. total kg dead	466,945	343,553	343,553
Number of mortalities	263,858	143,965	143,965
Total kg dead % of live kg harvested	11.8%	7.9%	7.9%
Kg harvested (live weight)	3,966,004	4,373,180	4,373,180
Yield kg live per released smolt	3.97	4.37	4.37
Total cost in box	61.75	62.24	54.62
eFCR per kg live produced	1.34	1.31	1.31
Total kg live produced per MAB-year	1,283,060	1,341,289	1,341,289
Total kg harvested HOG per MAB-year	1,316,248	1,554,576	1,554,576
EBIT MNOK per MAB-year	40,196,505	47,875,414	57,764,857
EBIT (NOK/kg) HOG	12.14	13.11	15.82

*The table presents key sustainability metrics for different post smolt strategies. These metrics help compare the sustainability and economic performance of traditional 100g smolts versus RAS and EGG 600g post smolts.

4.2 Facilitation for the New Post Smolt Strategies

Despite the CCS EGG emerging as a favoured strategy, it is clear that the current licensing and regulatory frameworks significantly impede innovation within the Norwegian aquaculture sector. According to research by Tveterås et al. (2021) for FLO SJØ and Stiim Aquaculture, the regulatory landscape for CCS finds itself in a regulatory limbo. This system does not align with the straightforward issuance of land-based licenses nor does it fit within the established traffic light system regulating open-net farming. Such regulatory misalignment places CCS at a competitive disadvantage by forcing it to compete within a framework that traditionally favours open-net operations and overlooks innovative approaches like CCS. Siri Vike, chief of fish welfare and health in Ovum AS, also underlines how the MAB and licensing regime favours those who build land-based facilities and do not have to pay for the permits (Furuset, 2024). This may be one of the reasons why CCS is not the preferred and obvious choice among most salmon farmers today.

However, our analysis highlights the substantial economic potential of CCS, as evidenced by the annual EBIT figures for the 9x post smolt generations. For instance, the 600 gram EGG generation boasts a remarkable improvement in EBIT per MAB-year, amounting to MNOK 10 more than its RAS counterpart. Moreover, this strategy results in an EBIT increase of MNOK 18,8 compared to the 100 gram benchmark generation.

A commonly used counterargument for not integrating CCS with existing open net operations is the high cost associated with the sea-based MAB permit. However, it is crucial to recognize the operational capacity of a single EGG unit, which can produce three cohorts annually, each consisting of 1 million 600 gram post smolts. This capability allows the CCS to generate a total annual EBIT of MNOK 56.4 across three cohorts when they are finally harvested, significantly outpacing the benchmark generation. With each post smolt cohort starting with 100 gram smolts and maturing into 600 gram, the average biomass per cohort is approximately 350 MT, substantially less than the standard permit of 780 MT MAB. Considering the market price for a full marine MAB permit of 780 MT is approximately MNOK 200, a half MAB would equate to a cost of MNOK 100. Our thesis reveals that, compared to the conventional strategy of releasing 100 gram smolts to open nets, adopting a CCS approach in Western Norway could yield an additional company EBIT of MNOK 100 after two years. Hence, even though the CCS strategy does not fully utilize the MAB, it remains more profitable than not implementing CCS, effectively maximizing returns on investment while minimizing operational costs.

In assessing the strategic shift to CCS for post smolt delivery, it is essential to understand the trade-off and gains in terms of both productivity and financial outcomes since it can seem like the farmer is foregoing the potential MT of live weight fish. Traditional open net pens allow for a MAB that can yield approximately 1,400 MT of live weight annually, as per the 2022 Kontali reported average productivity in Norway (Kontali, 2022). If we consider a scenario where half the standard MAB is utilized for conventional ongoing in open nets, this would produce about 700 MT of live weight per year. When converted to gutted weight, this translates into approximately 550 MT HOG, generating an annual EBIT of MNOK 20.1, assuming a margin of NOK 36.60 per kg gutted (Figure 5).

However, by integrating a CCS strategy despite using some production capacity for rearing larger smolts and hence potentially ”missing out” on this mentioned 550 MT HOG per year, the increased growth and reduced mortality rates inherent in post smolt strategies compensate for this apparent shortfall that companies might fear. This transition to post smolt strategies, particularly with CCS, may as seen, result in constant lower inventory costs and enhance both productivity and profitability throughout the production cycle.

These economic insights underline the pressing need for regulatory reforms that accommodate and promote CCS technologies. Adjustments in licensing regulations and facilitation are essential not only to foster innovation, but also to unlock significant economic benefits for the aquaculture sector in Norway. By aligning regulatory frameworks more closely with the capabilities and benefits of CCS, Norway can be leading in sustainable aquaculture, setting global standards.

4.2.1 Aligning Licenses with the Land-based Licenses

The current differences in licensing between land-based and CCS significantly hamper the adoption and development of innovative CCS technologies. Unlike land-based operations, which benefit from cost-free licensing, CCS initiatives face substantial financial barriers due to licensing costs. Aligning CCS licensing with the ”cost-free” permit of land-based operations could lead to a broader uptake of CCS technologies like the EGG. Offering free licenses for CCS would serve as a strong incentive for the industry, promoting environmentally beneficial practices while supporting a strategic shift towards ecological sustainability. Such a policy would motivate a broader spectrum of operators to adopt CCS, accelerating the sector's progress towards embracing more sustainable and environmentally conscious practices.

4.2.2 Environmental Technology Permits (Miljøteknologiordning)

In 2021, the Norwegian government introduced the environmental technology permits scheme. The concept was to give permits to companies that have zero sea lice and at least 60% waste collection - criteria well-suited to operations like the CCS EGG. This permit scheme builds on a 2015 initiative aimed at fostering technological solutions to environmental challenges in the industry. Despite these intentions, the 2023 report by the Aquaculture Committee did not endorse the continuation of the environmental technology permit, but rather suggested an environmental flexibility scheme (NOU 2023:23, 2023, p.55-113). It is designed to facilitate the deployment of low-emission technology in regions where emission reductions are essential. The environmental flexibility scheme allows operators to utilize a higher MAB limit on the company's permits, given that qualifying environmental technology is employed.

However, this scheme largely benefits current license holders and poses significant challenges for new entrants, who find themselves competing in license auctions against established operators with more traditional - and initially cheaper - technologies. This competitive disadvantage risks innovative ideas, and production technologies remain unexplored. Following recent developments, the Norwegian Parliament mandated on the 30th of April 2024 that the government must return by the end of 2024 with a proposal for a technology-neutral environmental flexibility scheme. This new proposal aims to address the recommendations of the Aquaculture Committee by fostering a more inclusive and innovation-friendly regulatory environment (Olsen, 2024).

4.2.3 Conversion Schemes

Within the aquaculture sector, conversion schemes have been proposed as a way to increase permissible production volumes under existing licenses by factors of 2 or 2.5. Such a conversion scheme represents a strategic incentive, encouraging greater investment in CCS and other innovative environmentally sustainable production technologies. A report from Menon Economics identifies that conditioned conversion schemes emerge as the most relevant tool for optimizing value creation within the industry (Grønvik and Grünfeld, 2021).

These schemes should enforce clear, functional environmental and welfare requirements, enabling operators to adopt cost-effective solutions that meet these criteria while ensuring technological neutrality. The report also recommends implementing strict limits on lice infestations and new benchmarks for mortality and environmental emissions. This reinforces the sector's commitment to both environmental sustainability and animal welfare, which again favours the EGG technology.

4.2.4 Pricing of Licenses

Dag Sletmo, a senior analyst at DNB, emphasized in an interview with IntraFish (Olsen, 2024) the critical need for reevaluating license and permit pricing to encourage investment in closed or semi-closed aquaculture systems. Sletmo pointed out that current licensing is predicated on conventional technology, which unfairly disadvantages CCS technologies, consistent with the core insights from the Stiim Aquaculture report. Sletmo advocates for regulatory incentives that bridge this gap, recognizing the environmental benefits and technological advancements of more sustainable systems like CCS.

Such reforms would not only address these disparities, but also foster innovation and competitiveness in the sector by offering a more transparent and fair route for deploying advanced, sustainable technologies like the CCS EGG. These regulatory modifications are crucial for leveraging the complete advantages of closed systems and charting a course towards a more sustainable, productive, and competitive future for Norwegian aquaculture. To harness the full potential of CCS and similar technologies, a multifaceted approach involving regulatory adjustments, transparent incentive structures, and supportive policies is essential.

Enhanced regulatory support and transparent incentive structures are imperative to maximize the potential of CCS and similar technologies. Initially, companies might consider acquiring and leasing a few CCS units to allow their sea-based production teams to familiarize themselves with the new system, evaluate its effectiveness, and refine operational strategies. Given the promising outcomes associated with early CCS adoption, companies should also contemplate delaying or reassessing investments in land-based RAS platforms.

4.3 Future Implications

The adoption of post smolt strategies has significant implications for the future of the Norwegian aquaculture industry. One immediate benefit is the potential improvement in managing mortality rates and mitigating sea lice impacts, which could lead more production areas to attain a ”green light” status under the current traffic light system. This improvement would permit a 6% expansion in company-based regional MAB permits. Given the existing challenges - five regions currently under a ”yellow light” and two under a ”red light” - there is considerable scope for enhancement.

Furthermore, the adaptability of CCS and RAS in post smolt strategies extends beyond national borders, offering valuable opportunities for global sustainable aquaculture development. Emerging aquaculture nations could look to the Norwegian model, adapting these strategies to fit local environmental and economic conditions. This adaptability enhances resilience and promotes sustainability, potentially fostering international collaboration, knowledge exchange, and diversification of food production methods. Such initiatives align with the United Nations Sustainable Development Goals (SDG), particularly SDG 14, which advocates for the sustainable management and protection of marine and coastal ecosystems from pollution (United Nations, n.d.).

Moreover, as global environmental regulations tighten, Norway‘s proactive adoption and promotion of these strategies could set a benchmark for worldwide aquaculture practices, encouraging a broader shift towards sustainability. The ongoing development and dissemination of these methodologies are poised to enhance the sustainability, efficiency, and profitability of aquaculture, thereby reinforcing its role in securing global food security. By embracing these advanced practices, Norway not only contributes to SDG 14, but also supports SDG 2 (Zero Hunger), which focuses on promoting sustainable food production systems and resilient agricultural practices (United Nations, n.d.). Expanding the scale of production for the aquaculture industry can lead to even further growth opportunities for increased production (Asche et al., 2018). Given the fact that the Norwegian aquaculture industry stands as one of the world's most efficient and sustainable producers of protein, this provides a leap in the right direction for the future (Norwegian Seafood Council, 2021).

The MAB-year metric has emerged as an important KPI in the analysis of aquaculture productivity, particularly in the context of innovative post smolt strategies. As the industry evolves with advanced rearing techniques that promise substantial improvements in productivity, traditional metrics often fall short of capturing the full impact of these innovations on operational efficiency and environmental sustainability. Incorporating MAB-year into performance evaluation empowers companies to make more informed decisions about their operations. By understanding their biomass utilization over time, managers can optimize feeding practices, adjust stocking densities, and schedule harvests more efficiently, all of which can lead to cost reductions and increased yield per cycle.

4.4 Why isn't CCS the preferred choice today?

Despite the economic benefits demonstrated by CCS, the aquaculture industry continues to favour RAS and traditional open net pens. However, given the significant economic advantages of CCS, why are more companies not adopting this technology? Stakeholders might fear losing their strategic advantage tied to Norway's fjord environments, as a shift to CCS could change their role from fish suppliers to technology providers, potentially altering market dynamics and business models. Additionally, there may be a reluctance to disrupt traditional practices. This industry has long traditions in fish farming production that might be hard for stakeholders to let go of, which could slow down the adoption of new technologies. One obvious reason RAS is the preferred choice today is that the technology is more mature and widely accepted, with established infrastructure and expertise readily available, reducing perceived risks associated with operational changes. Furthermore, some companies have enough permits but lack suitable locations, making CCS potentially the only viable option for them. Experienced farmers are well aware of the risks associated with adapting the new production methods and the challenges of being early adopters. Nova Sea AS and FishGLOBE AS serve as an example of this, where Nova Sea AS signed a contract with the producer of the CCS, FishGLOBE AS, only after successfully completing 14 test generations of farmed salmon (iLaks, 2024). This careful yet committed approach demonstrates that experienced farmers are cautious but also willing and ready to invest in promising new technologies.

4.5 Recommendations for Future Research

The role of CCS in promoting sustainable growth within Norwegian aquaculture is clear. The integration of various technologies within CCS opens up new sea areas and optimizes the utilization of existing localities. This is particularly relevant for our analysis, which focuses on Western Norway, characterized by production regions marked with "yellow" or "red" light. Implementing a new localization strategy, which strategically places CCS facilities to leverage geographic and environmental advantages, will be advantageous in this context.

While this thesis presents a structured analysis approach to implementing various post smolt strategies, multiple aspects warrant deeper investigation to fully understand the intricacies involved. Future studies should expand beyond the baseline and RAS generations compared to the CCS EGG by Ovum AS, exploring additional CCS technologies that could enhance environmental benefits, cost efficiency, and scalability. This broader scope will be essential as the landscape of aquaculture technologies continues to evolve.

Furthermore, considering the specific seasonal focus of our study on springtime smolt releases, subsequent research could benefit from examining how different seasonal strategies affect growth rates and overall sustainability. It would also be beneficial for future studies to include a detailed environmental impact assessment of adopting larger post smolt sizes and implementing various CCS and RAS technologies. Such assessments should thoroughly evaluate the implications for local ecosystems, biodiversity, and the broader environmental footprint, including carbon emissions. Future research can in this way provide deeper insight and more robust solutions to the challenges facing modern aquaculture. This will not only aid in refining current practices, but also help in shaping policies that support sustainable growth and innovation in the industry.

Given its potential to revolutionize biomass management, further research into the implementation and impacts of the MAB-year metric is crucial. Studies could explore its correlation with economic outcomes, ecological footprints, and compliance with international sustainability standards. Wider industry adoption of this metric, supported by empirical research and policy alignment, could significantly enhance the transparency, sustainability, and profitability of aquaculture operations globally.

Appendix A Input parameters for the different post smolt strategies

A.1 Common input for all smolt strategies

Input 1: Costs Model - Smolt and Post Smolt Harvest at 5kg

Parameter	Number	Explanation
Site parameters		
Region	Vestlandet, Norway	We have chosen Vestlandet as our region, because it is one of the most challenging areas to do fish farming and one of the areas that are in great need of change for a more sustainable production.
Start date	01.04.2024	Smolt placed in open net pens at this date
Generation parameters		
Smolt weight	100-, 200-, 400-, 600-, 800 grams	Weight at which smolt is placed in open net pens
Number of smolt	1,000,000	Placed in open net pens
Planned harvested weight	5,000g	All the generations will be harvested when reached this weight
Number of cages	8	From Knut Senstad Economic Fish Farming Model
bFCR	1.20	From Knut Senstad Economic Fish Farming Model
Feed cost (NOK/kg)	NOK 20.00	Estimated by Skretting for 2024 (From Boerge Pedersen at Skretting, date 08.02.24)
Start-up and cost parameters		

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Input 1 (continued): Input Costs Model - Smolt and Post Smolt Harvest at 5kg

Parameter	Number	Explanation
Generation start up cost, ex smolt	NOK 5,970,540	Costs related to the preparation for new generations, including disinfection/cleaning of nets, service maintenance and installation among other (1 million). And also the Fixed costs and depreciation costs for the fallow period: 9,257,143/4 mnd = 2,314,285 for 3 mnd (fallow period) 10,625,022/4mnd = 2,656,255 for 3 mnd (fallow period)
Wages per site per year	NOK 10,625,022	Estimated 3 people per week - one week on, one week of. Estimated base salary to NOK 650,000. Allocating NOK 1,000,000 for extra pay for net handling, sea lice treatment, etc.
Insurance, NOK/fish	NOK 10.00	From Knut Senstad Economic Fish Farming Model
Insurance, NOK/kg	NOK 17.00	From Knut Senstad Economic Fish Farming Model
Insurance premium, % of value	1.50%	Only live fish will accumulate in the insurance premium
Variable production costs		
Disposal cost per kg mortality	NOK 2.00	From Knut Senstad Economic Fish Farming Model
Wellboat cost per harvested kg	NOK 1.50	From Knut Senstad Economic Fish Farming Model
Processing cost per kg HOG	NOK 3.75	From Knut Senstad Economic Fish Farming Model
Public market fee	0.60%	From Knut Senstad Economic Fish Farming Model
Transport cost per kg HOG, FOB Oslo	NOK 1.65	From Knut Senstad Economic Fish Farming Model. The production fee per kilo implemented in kilo is nok 0,90 per kilo. production tax. Overall calculation included the newly added production tax.

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Input 1 (continued): Input Costs Model - Smolt and Post Smolt Harvest at 5kg

Parameter	Number	Explanation
Variable production costs		
Starvation weight loss	3.00%	From Knut Senstad Economic Fish Farming Model
Blood weight loss	2.00%	From Knut Senstad Economic Fish Farming Model
Gutted weight loss	11.50%	From Knut Senstad Economic Fish Farming Model
Sales parameters		
Superior grade	93%	From Knut Senstad Economic Fish Farming Model. Flawless, defect-free, not wounded, fine fins
Ordinary grade	5%	From Knut Senstad Economic Fish Farming Model. Minor flaws
Production grade	2%	From Knut Senstad Economic Fish Farming Model. More serious quality defects. Wounds on the skin, hence it can not be exported
Superior market price per kg	NOK 100.00	Average superior market price (3-6kg interval) - retrieved from Søren Martens (CEO), Fishpool, date 06.02.24
Ordinary market price per kg	NOK 98.50	Average ordinary market price (3-6kg interval) - retrieved from Søren Martens (CEO), Fishpool, date 06.02.24
Production market price per kg	NOK 80.00	Average production market price (3-6kg interval) - retrieved from Søren Martens (CEO), Fishpool, date 06.02.24

A.2 Traditional smolt

Input 2: **Costs Model - Open Net 100 gram Traditional Post Smolt Harvest 5kg**

Parameter	Number	Explanation
Generation parameters		
Smolt cost	NOK 16	From Knut Senstad Economic Fish Farming Model
Accumulated expected mortality, ex lice management strategy	16%	Production region 2 to 5, has a yearly total loss ranging from 17,0% up to 25,5% (Norwegian Veterinary Institute, 2024). However, this includes the loss connected to sea lice treatment. Basis mortality ex. mortality connected to the lice management strategy in Vestlandet is 16%.
Start-up and cost parameters		
Fixed costs, annual	NOK 15,106,400	-
Depreciation cost, annual	NOK 9,257,143	Appendix Table 4

A.3 EGG post smolt

Input 3: **Costs Model - 200 gram EGG Post Smolt Harvest 5kg**

Parameter	Number	Explanation
Generation parameters		
Smolt cost	NOK 21.56	From Knut Senstad Economic Fish Farming Model - EGG output data calculations
Accumulated expected mortality, ex lice management strategy	14.6%	Calculated by using the basis mortality in 100g post smolt, adjusted for the % time reduction in sea (See table in the ocean phase for the 9x gen.)
Start-up and cost parameters		
Fixed costs, annual	NOK 15,106,400	-

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Input 3 (continued): Input Costs Model - Open Net 200 gram EGG Post Smolt Harvest 5kg

Parameter	Number	Explanation
Depreciation cost, annual	NOK 9,257,143	Appendix Table 4

Input 4: Costs Model - 400 gram EGG Post Smolt Harvest 5kg

Parameter	Number	Explanation
Site parameters		
Generation parameters		
Smolt cost	NOK 27.38	From Knut Senstad Economic Fish Farming Model - EGG output data calculations
Accumulated expected mortality, ex lice management strategy	12.8%	Calculated by using the basis mortality in 100g post smolt, adjusted for the % time reduction in sea (See table in the ocean phase for the 9x gen.)
Start-up and cost parameters		
Fixed costs, annual	NOK 15,106,400	-
Depreciation cost, annual	NOK 9,257,143	Appendix Table 4

Input 5: Costs Model - 600 gram EGG Post Smolt Harvest 5kg

Parameter	Number	Explanation
Generation parameters		
Smolt cost	NOK 33.18	From Knut Senstad Economic Fish Farming Model - EGG output data calculations
Accumulated expected mortality, ex lice management strategy	10.7%	Calculated by using the basis mortality in 100g post smolt, adjusted for the % time reduction in sea (See table in the ocean phase for the 9x gen.)

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Input 5 (continued): Input Costs Model - Open Net 600 gram EGG Post Smolt Harvest 5kg

Parameter	**Number**	**Explanation**
Start-up and cost parameters		
Fixed costs, annual	NOK 15,106,400	-
Depreciation cost, annual	NOK 9,257,143	Appendix Table 4

Input 6: Costs Model - 800 gram EGG Post Smolt Harvest 5kg

Parameter	**Number**	**Explanation**
Generation parameters		
Smolt cost	NOK 37.18	From Knut Senstad Economic Fish Farming Model - EGG output data calculations
Accumulated expected mortality, ex lice management strategy	9.4%	Calculated by using the basis mortality in 100g post smolt, adjusted for the % time reduction in sea (See table in the ocean phase for the 9x gen.)
Start-up and cost parameters		
Fixed costs, annual	NOK 14,606,400	Expected a reduction in fixed annual costs since we no longer have small smolt or post smolt in the sea. This means we only require large net pens instead of both small and large net pens.
Depreciation cost, annual	NOK 9,257,143	Appenix Table 4. Expected a reduction in fixed annual costs since we no longer have small smolt or post smolt in the sea. This means we only require large net pens instead of both small and large net pens.

A.4 RAS post smolt

Input 7: Costs Model - 200 gram RAS Post Smolt Harvest 5kg

Parameter	Number	Explanation
Generation parameters		
Smolt cost	NOK 25.00	Calculated by adjusting the cost for the generation time which is reduced by 9% from 100g smolt (200g x 0.09 + survival cost NOK 7 = NOK 25)
Accumulated expected mortality, ex lice management strategy	14.6%	Calculated by using the basis mortality in 100g post smolt, adjusted for the % time reduction in sea (See table in the ocean phase for the 9x gen.)
Start-up and cost parameters		
Fixed costs, annual	NOK 15,106,400	-
Depreciation cost, annual	NOK 9,257,143	Appendix Table 4

Input 8: Costs Model - 400 gram RAS Post Smolt Harvest 5kg

Parameter	Number	Explanation
Generation parameters		
Smolt cost	NOK 43.00	Calculated by adjusting the cost for the generation time which is reduced by 9% from 200g smolt (400g x 0.09 + survival cost NOK 7 = NOK 43)
Accumulated expected mortality, ex lice management strategy	12.8%	Calculated by using the basis mortality in 100g post smolt, adjusted for the % time reduction in sea (See table in the ocean phase for the 9x gen.)
Start-up and cost parameters		
Fixed costs, annual	NOK 15,106,400	-
Depreciation cost, annual	NOK 9,257,143	Appendix Table 4

Input 9: **Costs Model - 600 gram RAS Post Smolt Harvest 5kg**

Parameter	Number	Explanation
Generation parameters		
Smolt cost	NOK 61.00	Caculated by adjusting the cost for the generation time which is reduced by 9% from 400g smolt (600g x 0.09 + survival cost NOK 7 = NOK 61)
Accumulated expected mortality, ex lice management strategy	10.7%	Calculated by using the basis mortality in 100g post smolt, adjusted for the % time reduction in sea (See table in the ocean phase for the 9x gen.)
Start-up and cost parameters		
Fixed costs, annual	NOK 15,106,400	-
Depreciation cost, annual	NOK 9,257,143	Appendix Table 4

Input 10: **Costs Model - 800 gram RAS Post Smolt Harvest 5kg**

Parameter	Number	Explanation
Generation parameters		
Smolt cost	NOK 79.00	Calculated by adjusting the cost for the generation time which is reduced by 9% from 600g smolt (800g x 0.09 + survival cost NOK 7 = NOK 79)
Accumulated expected mortality, ex lice management strategy	9.4%	Calculated by using the basis mortality in 100g post smolt, adjusted for the % time reduction in sea (See table in the ocean phase for the 9x gen.)
Start-up and cost parameters		

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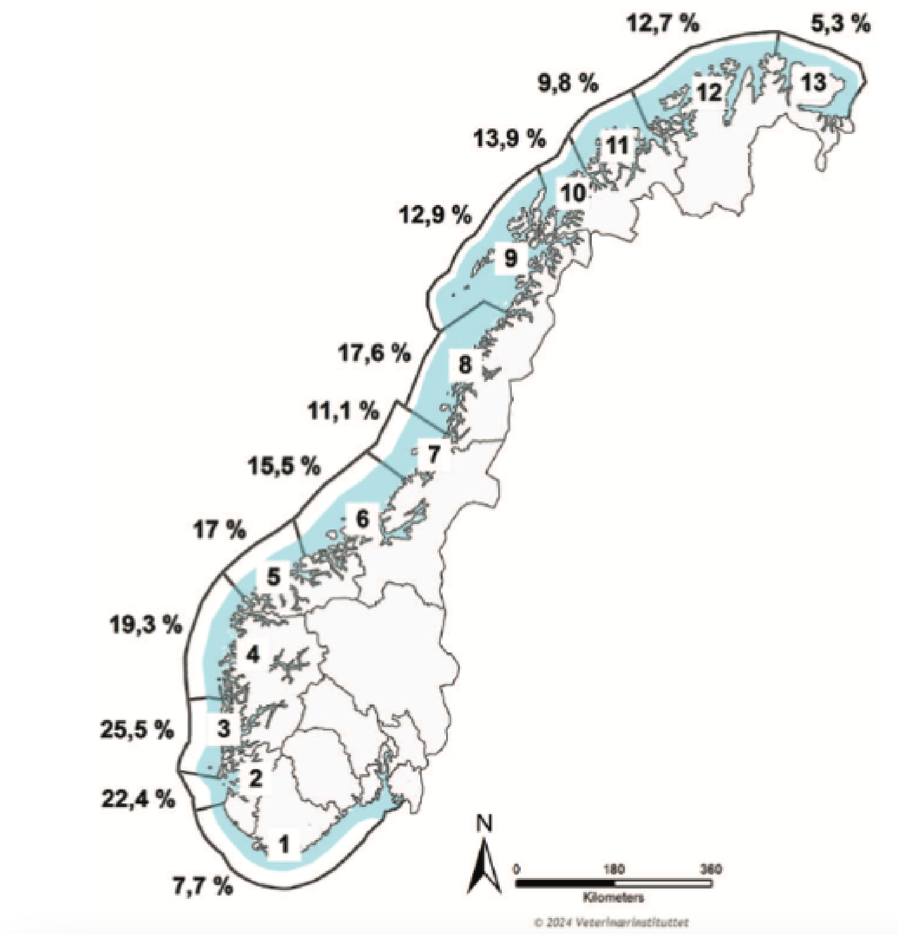
Input 10 (continued): Input Costs Model - Open Net 800 gram RAS Post Smolt Harvest 5kg

Parameter	Number	Explanation
Fixed costs, annual	NOK 14,606,400	Expected a reduction in fixed annual costs since we no longer have small smolt or post smolt in the sea. This means we only require large net pens instead of both small and large net pens.
Depreciation cost, annual	NOK 9,257,143	Appendix Table 4. Expected a reduction in fixed annual costs since we no longer have small smolt or post smolt in the sea. This means we only require large net pens instead of both small and large net pens.

Appendix B Figures

Figure 1: Production Areas in Norway*



* A map over the different production areas in Norway retrieved from the Risk Report Norwegian Fish Farming 2023 ((Institute of Marine Research, 2023a))

Figure 2: Benchmark 100 gram Smolt, Cost in Box and Operating Margin in NOK

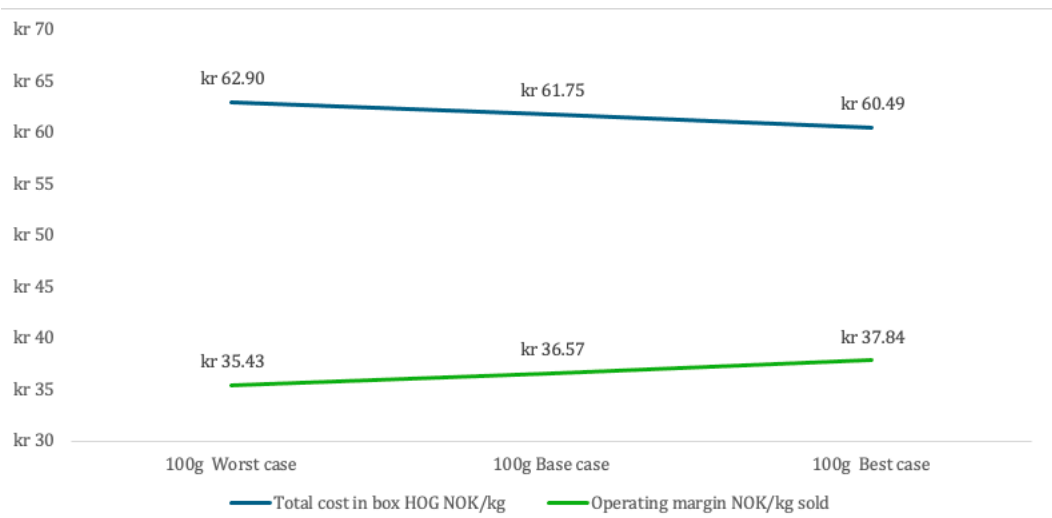


Figure 3: 600 gram RAS Post Smolt, Cost in box and Operating Margin in NOK

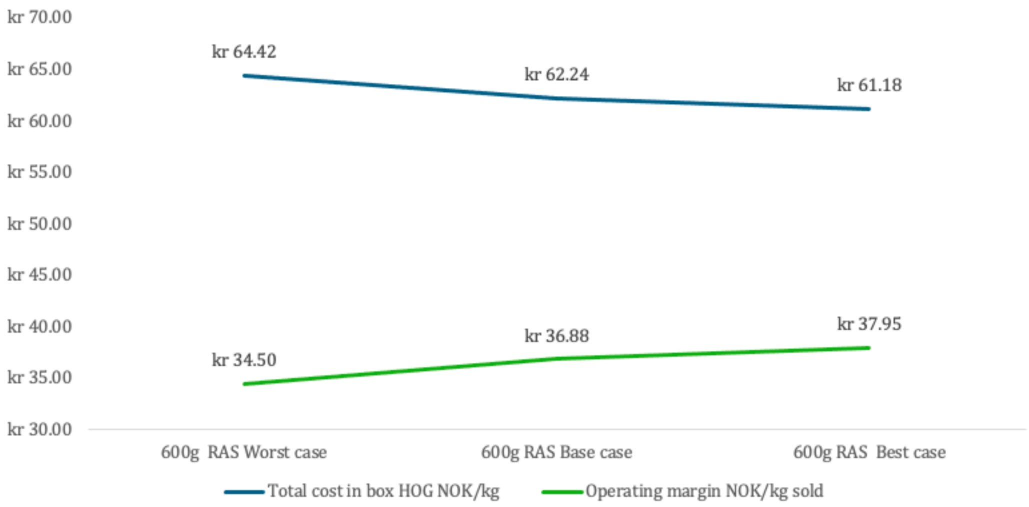
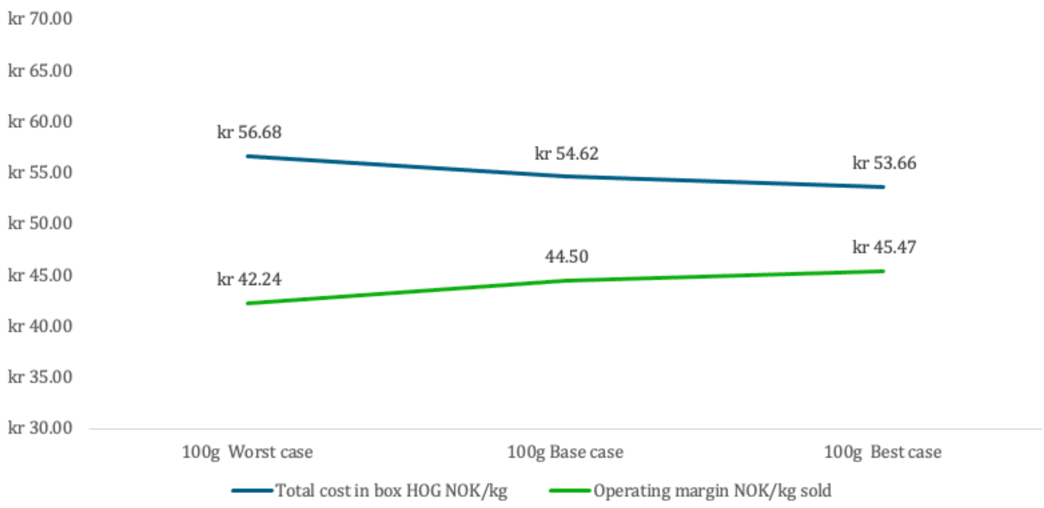


Figure 4: 600 gram EGG Post Smolt, Cost in Box and Operating Margin in NOK



Appendix C Tables

Table 1: General Information per Production Region

Indicator for 2023	P2	P3	P4	P5	Total
Average # localities	40	125	118	37	320
# Released Salmon (millions)	21	47	34	16	118
Avg. Monthly Biomass (MT)	44.757	82.284	53.742	37.331	218.114
For harvest (MT)	85,430	152,150	123,891	99,730	461,201
Temperature Summer	15-16	15-16	15-16	15	15-16
Temperature Winter	4-5	5-6	5-6	5-6	5-6
Mortality (%)	19.5	23.7	22.0	17.7	20.7

Table 2: Time Reduction and Effect on Mortality for Each Generation of Post Smolt

Generation	# Weeks	# Months	% -Time Reduction	# of Sea Lice Treatments	Baseline Mortality
100g smolt	70	16.3	-	6	16.0%
200g RAS	64	14.9	91.4%	6	14.6%
400g RAS	56	13.0	87.5%	4	12.8%
600g RAS	47	10.9	83.9%	2	10.7%
800g RAS	41	9.5	87.2%	1	9.4%
200g EGG	64	14.9	91.4%	6	14.6%
400g EGG	56	13.0	87.5%	4	12.8%
600g EGG	47	10.9	83.9%	2	10.7%
800g EGG	41	9.5	87.2%	1	9.4%

Table 3: Sea Lice Treatment Simulation

Production Method	**# Weeks in Sea**	**Sea Lice Treatment**	**Mortality (%)**
100g smolt	70	6	5.2
200g RAS	64	6	5.2
400g RAS	56	4	3.5
600g RAS	47	2	1.8
800g RAS	41	1	0.9
200g EGG	64	6	5.2
400g EGG	56	4	3.5
600g EGG	47	2	1.8
800g EGG	41	1	0.9

Table 4: CAPEX and start up costs Open Net farming 100-600 gram (7 years depreciation)

Element	**CAPEX per unit (NOK)**	**# units**	**Sum CAPEX (NOK)**
Feedbarge	12,500,000	1	12,500,000
Serviceboat	7,500,000	1	7,500,000
Moorings	5,000,000	1	5.000.000
Landbase	-	-	-
Forklift	500,000	1	500,000
Crane landbase	500,000	1	500,000
Ensilage tank	-	-	-
Cages	1,250,000	8	10,000,000
Smolt nets	-	-	-
Ongrowing nets	-	-	-
Camera sensors	2,000,000	1	2,000,000
Grading nets and mics	1,000,000	1	1,000,000
Miscellaneous	2,000,000	1	2,000,000
Sum CAPEX NOK	32,250,000		41,000,000

Table 5: CAPEX and start up costs Open Net farming 100-600 gram (15 years depreciation)

Element	**CAPEX per unit (NOK)**	**# units**	**Sum CAPEX (NOK)**
Feedbarge	17,500,000	1	17,500,000
Serviceboat	17,500,000	1	17,500,000
Moorings	-	-	-
Landbase	5,000,000	1	5,000,000
Forklift	-	-	-
Crane landbase	-	-	-
Ensilage tank	1,000,000	1	1,000,000
Cages	-	-	-
Smolt nets	250,000	10	2,500,000
Ongrowing nets	250,000	10	2,500,000
Camera sensors	-	-	-
Grading nets and mics	-	-	-
Miscellaneous	5,000,000	1	5,000,000
Sum CAPEX NOK	46,500,000		51,000,000

Table 6: CAPEX and start up costs Open Net farming 800 gram (7 years depreciation)

Element	**CAPEX per unit (NOK)**	**# units**	**Sum CAPEX (NOK)**
Feedbarge	12,500,000	1	12,500,000
Serviceboat	7,500.000	1	7,500,000
Moorings	5,000,000	1	5,000,000
Landbase	-	-	-
Forklift	500,000	1	500,000
Crane landbase	500,000	1	500,000
Ensilage tank	-	-	-
Cages	1,250,000	8	10,000,000
Smolt nets	-	-	-
Ongrowing nets	-	-	-
Camera sensors	2,000,000	1	2,000,000
Grading nets and mics	1,000,000	1	1,000,000
Miscellaneous	2,000,000	1	2,000,000
Sum CAPEX NOK	32,250,000		41,000,000

Table 7: CAPEX and start up costs Open Net farming 800 gram (15 years depreciation)

Element	**CAPEX per unit (NOK)**	**# units**	**Sum CAPEX (NOK)**
Feedbarge	17,500,000	1	17,500,000
Serviceboat	17,500,000	1	17,500,000
Moorings	-	-	-
Landbase	5,000,000	1	5,000,000
Forklift	-	-	-
Crane landbase	-	-	-
Ensilage tank	1,000,000	1	1,000,000
Cages	-	-	-
Smolt nets	-	-	-
Ongrowing nets	250,000	10	2,500,000
Camera sensors	-	-	-
Grading nets and mics	-	-	-
Miscellaneous	5,000,000	1	5,000,000
Sum CAPEX NOK	46,500,000		48,500,000

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