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Mobile slaughterhouses at sea

Do stun-and-bleed vessels meet Norwegian salmon farming requirements?

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Preface

In the NTNU course *TMR4254 - Design of Marin Systems* in 2017 I worked with a group of co-students on a group project where we used the *System Based Ship Design* method by Kai Levander (2012) to design a live fish carrier (LFC). At the time, uncertainty related to the future of the LFCs existed in the industry. The Norwegian LFC market seemed to be heading toward overcapacity, with several new vessels entering the market. The growth of production volumes in Norwegian salmon farming had been slowing down since 2012. However, the LFC market seemed to be thriving, with most LFC owners increasing their sales of services each year. As of 2020, this development continues, with larger and more complex LFC systems entering the market.

An alternative to transporting harvest salmon did exist in 2017, using specialized vessels that could kill the fish onboard, thereby moving part of the function of a salmon slaughterhouse out to the production sites. I learned that the company i was working in part time, Moen Marin, were planning on designing SBVs for customers in February 2019, and I decided that I wanted to write my master thesis on the subject of design of this new type of vessel.

The master's thesis has been written with the support of Moen Marin AS. The company has supplied advice and updates on current stun-and-bleed projects.

Acknowledgements

During the work with my thesis, I have met and talked to several people within the Norwegian aquaculture industry. These meetings have been fruitful and helped me further my understanding of the industry. Of several possible directions, I decided to concentrate on the stun-and-bleed vessel technology and how they can meet the regulations and requirements in the Norwegian salmon aquaculture industry.

I would like to express my thanks to my supervisors at the Department of Marine Technology, Professor Bjørn Egil Asbjørnslett, for allowing me to write the thesis of my choice, and assistant Professor Svein Aanond Aanondsen for providing excellent counsel and understanding and for being available. The guidance and comments during the writing process were appreciated.

The talks and discussions with staff and specialists at the companies Moen Marin and Marin Design AS were valuable for the development of my thesis and points that I have stressed within it. I am grateful to Mr. Atle Hans Fyhn for all his inspirational advice and patience during our discussions.

I would like to thank my family in Tromsø for support throughout my time as a student, and in these initial weeks of 2020, particularly my father, Roger B. Larsen, assistant professor at UiT - The Arctic University of Norway.

Abstract

This thesis finds that stun-and-bleed vessels (SBVs) can meet the requirements of the Norwegian salmon farming industry. As a harvest vessel for salmon, the system type has many advantages over its counterpart, the live fish carrier (LFC). SBVs are more efficient, in the sense that they can transport more salmon per cargo space volume than LFCs. SBVs are more area-critical than LFCs of comparable size since more deck space is needed for an onboard processing plant. Still, an SBV with the same cargo capacity as an LFC has a size, measured in gross tonnage (GT), 60 % less than that of an LFC. The size difference implies lower building costs, emissions, and better fuel economy, allowing the owner of an SBV to offer better freight rates than LFCs to farmers. SBVs using low-temperature refrigerated seawater (RSW) to transport dead salmon delivers a chilled product to the slaughterhouse, which does not have to use excessive amounts of energy and time chilling the salmon (potentially affecting pre-rigor times).

An SBV is more suited for transporting salmon weakened due to diseases, such as Pancreas disease (PD) and Cardiomyopathy syndrome (CMS). A new regulation concerning salmon Salmon louse (*Lepeoptheirus salmonis*) could give SBVs a logistical advantage over LFCs as a choice of harvest vessel, as waiting-cages become less usable. The SBV kills the salmon immediately after loading it, thereby being better for fish welfare. The use of SBVs implies only one combined crowding and pumping operation for live salmon, while the use of an LFC implies at least two pumping operations and one crowding operation.

The number of individual salmon deaths at sea has been more than 40 million per year the past ten years, and due to new methods in ever-intensifying combat with parasites, the mortality of salmon in the sea phase causes financial losses of several billion NOK. Salmon farming companies that incorporate smaller, emergency type SBVs could reduce their alternative costs from losing salmon during treatment operations, such as delousing. Reducing the amount of dead salmon biomass at production sites could reduce the cost related to on-site silage (silage vessel transport fees, formic acid usage, and maintenance of systems). The fish processed by emergency SBVs could be used for human consumption, thereby increasing profits and overall sustainability.

Contents

List of Figures

List of Tables

Abbreviations

AGD	Amoebic gill disease
CMS	Cardiomyopathy syndrome
CO_2e	Carbon dioxide equivalent
FCR	Feed conversion ratio
HOG	Head-on-gutted
GT	Gross tonnage
ISA	Infectious salmon anemia
LFC	Live fish carrier
LWE	Live weight equivalent
MSD	Maximum stocking density
MPB	Maximum permitted biomass
NDF	The Norwegian Directorate of Fisheries
NFSA	Norwegian Food Safety Authority
NMA	Norwegian Maritime Authority
OPEX	Operational expenses
PD	Pancreas disease
SBV	Stun and bleed vessel
RSPCA	Royal Society for the Prevention of Cruelty to Animals
RSW	Refrigerated seawater
VOYEX	Voyage expenses
WFE	Whole fish equivalent

1 Introduction

1.1 Background for the thesis

The Norwegian Atlantic salmon (*Salmo salar*) aquaculture grew at a near exponential rate in the years 2000-2012, in both production volume and value. From 435 000 tonnes of salmon worth 10.9 billion NOK to 1.23 million tonnes (an average yearly increase of >9 %) worth 28 billion NOK [3]. During the same period, the need for vessels offering seaborne transportation of salmon, to and from the open sea production cages, naturally grew in both number and cargo volume. These vessels transport live salmon and are called *wellboats* or *Live Fish Carriers* (LFCs). In 2000, the largest LFCs had a cargo volume of approximately 1000 m^3. By 2013 the worlds largest LFC had a cargo volume of 4500 m^3 [4].

At the end of the last decade, there was great optimism in growth potential for the Norwegian salmonid farming industry. Production was stipulated to increase from 1 million tonnes in 2010 to 5 million tonnes by 2050 (assuming an average of four percent growth in production volume each year) [5]. 2011 and 2012 indicated a promising start, with Atlantic salmon production volume increases of 13.3 % and 15.7 %, respectively [3]. Since 2013 this has not been the case, though, as the increase in production volumes has stagnated. The yearly growth in production volumes was averaging only 0.8 % in the period 2013-2018 (varying between -5 % and 7.7 %).

With the apparent reduction in production growth rate, one might assume stagnation in need for seaborne transportation of salmon, and subsequently, a halt in new LFCs production. However, the LFC building business is still booming in 2020. New vessels with cargo volumes >2500 m^3 have become commonplace, the current largest vessel has a cargo volume of > 7000 m^3, and a LFC of 7500 m^3 is expected to be delivered in 2021 [6], [7]. There are several reasons for this. In 2017 the average age of the 76 vessels strong LFC fleet in Norway was 14 years [8]. Several of these vessels are more than 20 years old. New regulations from the Norwegian Food Safety Authority (NFSA) with regards to the treatment of transport water, entering into force from 2021, are expected to lead to a generational change in the Norwegian LFC fleet. The reasoning being that the need for modification and refitting older, smaller LFCs is not beneficial. Also, the smaller LFCs no longer meet the cargo capacity needed during harvesting and the raw material demands of the on-shore processing facilities. Due to welfare requirements for the transported salmon, the LFCs carry a maximum salmon to water weight ratio of 1:5, or at a stocking density of 150 kg live salmon per m^3 of seawater. The largest Norwegian on-shore processing facilities can process more than 300 tonnes of raw material every shift (eight hours) [2]. With a stocking density of 150 kg/m^3, this would entail the use of an LFC with a minimum cargo volume of 2000 m^3, delivering salmon once every 24 hours (assuming only one shift per workday). The operational profile of LFCs has also changed considerably in recent years. From only carrying out transport operations, LFCs are today used for sorting operations and removal of parasites, particularly the salmon louse (*Lepeophtheirus salmonis*). "Delousing" refers to a Salmon louse removal operation in this thesis.

These parasites, along with other ailments such as the infectious diseases Pancreas Disease (PD) and Infectious Salmon Anemia (ISA), have been literal plagues for the Norwegian salmon industry. Disease and parasites are known causes of salmon mortality during the on-growing phase at sea. In 2018 46.2 million individual salmon died in Norwegian sea cages [9]. The estimated median mortality of all individuals released into the sea was 15 % in 2017-2018. The mortality percentages in Norwegian salmon farming counties that year varied between 5.9 % (Agder) and 20.2 % (Hordaland). Salmon that dies before being killed by processing is unfit for human consumption. The lost biomass ends up as silage. Studies have shown that new mechanical methods for delousing operations are responsible for a considerable amount of the dead salmon in recent years [10]. Regulations dictate limitations for salmon transports, to prevent the spread of PD and ISA from infected zones [11]. It is illegal to place PD infected fish in open-net cages outside on-shore processing facilities (so-called "waiting" or "slaughtering" cages). PD, Cardiomyopathy syndrome (CMS), and many other infectious diseases can weaken the salmon, making it less robust towards delousing and transport [9], [12].

At the same time as LFCs are becoming larger and more technologically advanced in order to meet the increasing demands from Norwegian public authorities and salmon farmers, a technology from the past, involving the killing of salmon at the initiation of harvest operations (i.e., at the sea production sites) has had a comeback. Vessels that stun and kill the salmon after pumping them onboard can transport salmon more densely packed in their tanks. The first vessel using this technology at full scale was the modified LFC "Tauranga" [13]. In this thesis, these "mobile slaughterhouses" are referred to as stun-and-bleed vessels (SBVs). SBVs can, depending on the technology in use, process salmon that is weak before an operation (e.g., delousing) [14]. Alternatively, be put on standby, taking out, and processing salmon alongside the delousing operation.

SBVs with different operational profiles are currently under development and delivery. However, limited research relating to and experiences with the use of SBVs is available. Emerging vessel concepts and designs are varied in both size, capacity, and intended operational profile. The significant variation in design could be an indication that the companies that are building or contracting these vessels are uncertain of the requirements for what constitutes a well-designed SBV.

1.2 Problem description

Norwegian salmon farmers want a transport system that ensures the minimal loss of fish, and that does not negatively affect the quality of the product. LFCs have increased dramatically in size and complexity in order to meet customer and regulatory demands. As a means of transport for salmon, LFCs are inefficient, as less than 15 % of their cargo can be considered payload. Stricter regulation regarding disease control in Norwegian aquaculture has caused the LFCs to move from being primarily a transportation system to a multi-functional system. SBVs have several apparent advantages in transporting salmon, among others: Increased cargo capacity (more efficient), potentially increased welfare (fewer handling operations of live fish), more favorable as a means of transporting salmon weakened by PD and CMS

[12].

The main objective of this thesis is to map the requirements in the aquaculture industry, translate these into functional requirements, and to identify areas where stun and bleed technology can meet these requirements.

1.3 Objectives and scope of the thesis

Objectives

- Present an overview of the Norwegian Atlantic salmon transport situation today, including value chains for Atlantic salmon from release into sea cages and delivery to market.
- Present an overview of relevant preliminary ship design theory with a focus on requirement elucidation and handling of future uncertainty.
- Map the requirements related to vessels transporting Atlantic salmon in Norway, including salmon welfare and quality, Norwegian regulations, industry image, and sustainability.
- Identify and describe missions that could be performed by different vessel concepts using stun and bleed technology.
- Perform an in-depth analysis for the possibility of using SBVs in order to salvage salmon for human consumption, that otherwise would become silage. Identify regions in Norway that would most benefit from investing in this capability.
- Identify and present areas for further work related to SBVs that the scope of this thesis does not include.

Assumptions and limitations This thesis is limited to the Norwegian salmon farming industry, in open sea cages per 2020. Direct effects of vessel design on parts of value chain other than direct interfaces are not considered.

This thesis has no distinct customer that has put forward a set of requirements for a specific project or vessel design. The reason is twofold: 1) Not to restrain the process of identifying requirements that are general to the SBV concept and 2) avoid the use of confidential information, subsequently disclosing the thesis.

Farmed Atlantic salmon production forms the basis for the presented statistics and calculations that are related to economy, biomass, and markets. Rainbow trout is the second most important aquaculture species in Norway but has not constituted more than 5-7 % of total salmonid quantity sales in the period 2010-2019 [3], [15]. Theory related to biology also focuses on Atlantic salmon, e.g., not differentiating between effects of disease and parasites on Atlantic salmon and Rainbow trout.

1.4 Structure of this thesis

This thesis presents a description of the seaborne transportation of farmed salmon in Norway today and how salmon interacts with other parts of the salmon farming value chain (i.e., sea production facilities and slaughterhouses). A large part of this thesis focuses on how the biology of farmed Atlantic salmon dictates the requirements of transports vessels, and how the increasing challenges related to disease and parasites has been an essential driver for recent developments within treatment technologies. This thesis presents a broad mapping of requirements within the Norwegian aquaculture concerning its salmon transport systems. How SBVs can meet the modern transportation requirements in Norwegian aquaculture is examined. The thesis further explores how different vessel concepts can meet these requirements. Using theory for preliminary ship design as a basis for identifying requirements for an SBV to mitigate salmon death due to increased mortality.

2 Design Theory

This chapter presents important design aspects for ships in general, with a focus on the initial design phase. The chapter sheds some light on to the complexity of ship design, and why design decisions at the initial phases of ship design have to be well founded. The focus revolves around the idea of identifying the requirements for a new vessel design, particularly with a relatively novel design, as is the case for stun and bleed vessels. The last section in this chapter discusses market research as a part of the design process, using the Norwegian salmonid seaborne transportation market as an example.

2.1 The ship design process and its initial stages

The stages of a design process has been and is described in multiple ways. In a handbook from *The Association of German Engineers* divides the general approach to design into four phases consisting of seven stages [16]. The first phase consists of clarifying and defining the task (1). In the second phase functions and the structure of these is determined (2), as well as searching for solution principles and combinations of these (3), and dividing the design into realizable modules (4). Dividing into modules continues in phase four, which also consists of development of key module layout (5) and eventually complete overall layout (6). Finally, the product is ready for production preparation and operating instructions (7) in phase four. The approach also highlights the overlapping between each phase and the backwards and forwards iteration between each stage of design, in addition to a continuous evaluation of requirements fulfillment. With a focus on mechanical engineering, incorporating fundamentals of *technical systems*, fundementals of *the systematic approach*, and the *general problem solving process*, Phal et al. divides the planning and design process into four main phases [17]:

- Planning and task clarification: specification of information
- Conceptual design: specification of a principle solution (concept)
- Embodiment design: specification of layout (construction)
- Detail design: specification of product

Similarly ship design can be broken down into four phases; a) Concept design feasibility study, b) Preliminary design, c) Contract design, d) Detailed design [18]. The same iterative nature of design as described earlier is commonly found in models for the ship design process. Most famously illustrated by the design spiral of Evans [19]. It encompasses all ship design steps in a sequential order, from initial mission requirements, followed by estimation of main dimensions and machinery, calculation of hydrostatics and stability, arrangements, estimating lightship weight and cost estimates (to mention some). The process repeats itself multiple times, and by doing so the project moves through ship design phases a)-d). After the first loop the concept feasibility study may be complete, and mere approximate figures provides a faded idea of a solution. The design spiral has been criticized as it follows a "*design-evaluate-redesign*" structure [20]. It locks the designer to first assumptions and does not support innovation and creativity in order to explore alternatives.

Brown emphasizes that a ship's performance functions are "non-linear and often discontinuous" and that "inequalities are often more common than equations" [21]. This is not well represented by flow diagrams such as the design spiral. Brown was talking about *naval* vessels in particular, but is applicable to vessels that have no single function, which can be said for many ships today [20]. Several elaborated and altered versions of the design spiral have been put forward by others (e.g. Sen and Birmingham [22] and Rawson [23]). A version of the design spiral, put forward by Levander, "straightens" the design spiral, as seen in Figure 2.1. Part of the design process is still kept in an iterative loop. These include "form", "performance", and "economics"and incorporate most of the aspects that are found in modern day versions of Evans' design spiral.

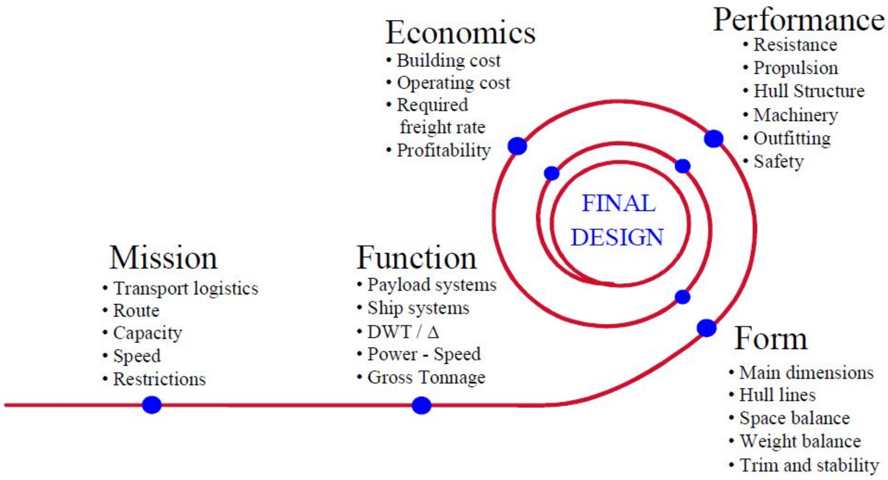


Figure 2.1: The ship design process as described by Levander [19].

The initial parts of the process, "mission" and "functions" are interestingly kept out of the loop, indicating that once defined they are not reevaluated during the design process. Specification of the mission, i.e. area of operation, cargo and payload capacity, limitations to the ship design (e.g. port draught restrictions) defines the task the ship is intended for. Preferences of the owner, machinery type, speed, important rules and regulations should be included in the mission statement. It is important to separate between "musts" and "wants" when defining the mission, or goal of the ship's task. Design criteria such a those imposed by national rules and regulations fall under the "musts", while "wants" are performance related. The mission statement forms the basis for a description of the ships functions, divided into "ship systems" and "payload systems" (see Figure 2.2). Functions can be met by choosing different types of systems (*functional carriers*), but when chosen these form the basis for calculating the space (both area and volume) needed to fulfill a function, thereby the ships task and overall mission.

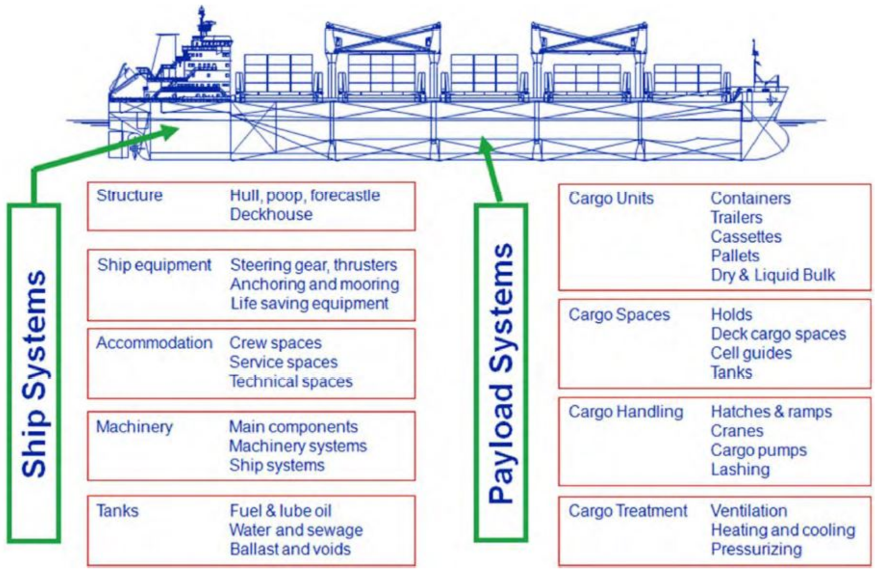


Figure 2.2: Example of payload and ship systems, serving functions on board a vessel [19].

Statistical data can be used to find relationships between important ship characteristics, e.g. a certain type of vessels gross tonnage (which can be derived from the total volume of a vessel) and deadweight. An obvious pitfall to this method is the assumption that the stated mission will not change considerably over time, or that the functions and subsequent systems chosen are the most appropriate solution. The issue with choice of suitable systems to solve the different functions can be mitigated with creative processes where several alternatives are evaluated and the best one chosen. If the mission statement is based on wrong assumptions or limited information all following work could be fruitless. Also, there is a lack of statistical data for certain types of vessels (e.g., live fish carriers (LFCs) and for newly emerging vessel types this method is not fully applicable as new designs vary quite a lot. Still, the method provides more alternatives and gives more weight to the initial phases of ship design than the design spiral.

The most crucial design phase for a vessel is arguably the initial phase, often referred to as both conceptual or preliminary phase. Design decisions made at this stage implicate 70 % or more of total production costs [24]. An illustrating of this can be seen in Figure 2.3. At the point of construction start the possibility to impact future costs of both construction, use and maintenance diminishes dramatically, and for a designer disappears completely as the vessel is put into use. Later life modifications may mitigate environmental impacts and costs but such interventions are costly. "At the beginning of the conceptual design, no decisions have yet been made, and the only constraints are the ones related to the top-level mission requirements. All subsequent decisions will constraint the design freedom." [25].

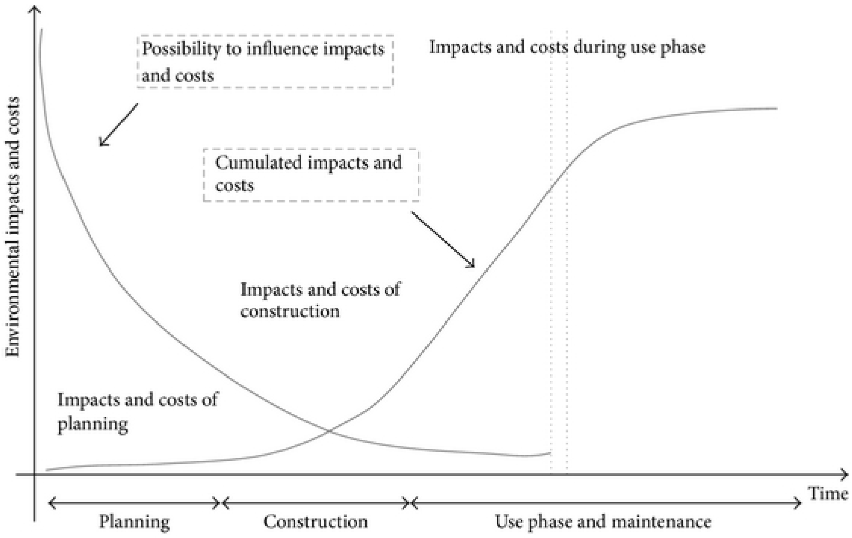


Figure 2.3: Influence of design decisions on life cycle impacts and costs [24].

Adopting an existing design or parent design is often an attractive approach to ship design to reduce the risk and cost of a project [26]. Keane argues for several pitfalls to this approach. The more the needs and requirements differ from the previous customer, the less applicable the previous design is. Implementing the use of a parent design will commonly lead to the adding or changing of ship systems. Changes from the parent design may prove problematic, especially if the parent solution is an exact solution, unforgiving to design deviations. "Design is a one-time process that can only add value when we do something different." [26].

2.2 Requirement elucidation

Andrews argues that "*the initial design phase is quite different in its objective. It is not about starting to work up a solution but to elucidate (primarily with the customer/requirement owner) the right (and affordable) set of requirements.*" [27]. Rigorous attempts at establishing functional hierarchies of complex systems such as ships, without specifying solutions for any functions can prove to be an unfruitful endeavor. Suh emphasizes that functional requirements cannot be broken down into sub-groups before determining the physical properties of the parent function [28]. In a paper from 2011, Andrews explains why a strictly *Requirements Engineering* approach to ship design is problematic [29]. Attempts to create "non-material solution specific" vessels have been made in both US and UK naval projects. The idea is to "write requirements that do not necessarily constrain the solution." In these cases, the emphasis has been on abstraction, "showing what the system will do but not how it will be done." Andrews argues that this is "counter-intuitive to designers of engineering physical systems (such as ships)."

Furthermore, physical solutions are necessary to arrive at non-material requirements, and deriving capabilities without cost and feasibility checks can lead to "dead-ends." [29]. Requirements are challenging to formulate and interwoven with the search for possible solutions. Instead of wholly refraining from physical solutions through *Requirements Engineering*, in which requirements for a system are put forward by a requirements owner to a designer, mutual dialogue with the designer is necessary for a project's success. This dialogue is referred to as *Requirements Elucidation.*

The first two phases in product planning and design, as described by Phal et al., result in the specification of a *requirements list* and a *principle solution* (concept), respectively [17]. All the phases and steps in a planning and design process are shown in Figure 2.4.

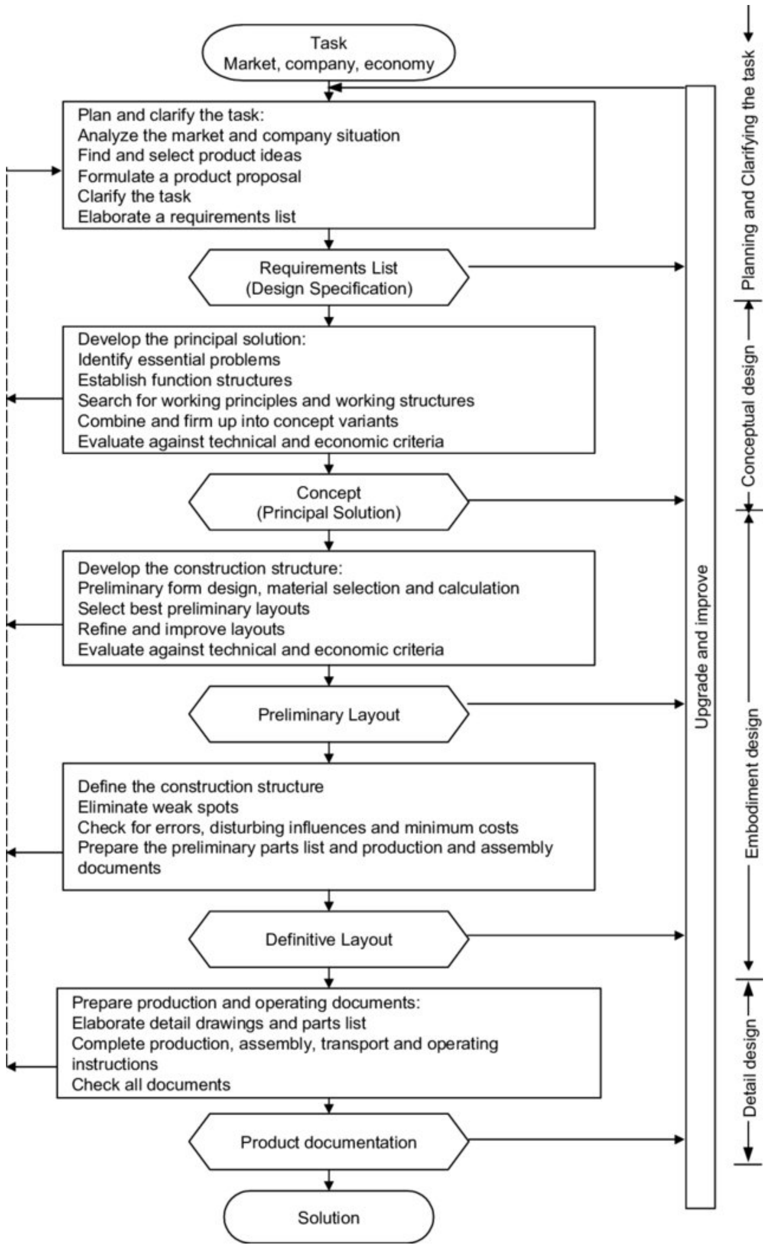


Figure 2.4: Steps in the planning and design process [16].

For a designer to create a requirements list, the design task must be clarified in such a manner that the requirement list "*represents the specification against which the success of the design project can be judged*" [17]. Questions like "What are the objectives that the design is expected to satisfy", "what properties must it have", and "what are the limitations" have to be answered in cooperation with the client. This communication or requirements elucidation forms the basis for the requirements list. Furthermore, before a list can be worked out, the designers should undertake the task of *situation analysis* or market research. Separating requirements into *demands* and *wishes* (or "musts" and "wants" as Levander divides customer specifications into) are important in order to assign importance to the requirements. Concepts that do not fulfill demands should be abandoned as soon as possible (an important reason for a comprehensive requirements list).

Wishes should be taken into considerations whenever possible but can e.g., be categorized as being of major, medium, or minor importance [17]. Requirements should also be sorted by their *qualitative* (permissible variations or special requirements) and *quantitative* (numbers and magnitudes) aspects. Requirements should be defined in as clear terms as possible. However, many or arguably, most requirements will not be available at the offset of the project and should, therefore, be reviewed and evaluated throughout the design process.

2.3 Market research in ship design

An essential aspect of ship design is to establish the economic viability of the project, and whether or not invested capital will yield good returns [30]. This research can be done through an analysis of the market with the aim of mapping market needs and demands, such as the demand for ships within the market, current and expected freight rates, expected cargo quantities, and trends within the market. In general, designers conduct market research in order to assess current requirements and future markets for products [31]. In the case of this thesis, this means requirements for salmon transportation systems (i.e., vessels) and the future market for these.

"*The purpose of market research is to reveal the demand for a service*" [32]. Both general market conditions and specific customer conditions may influence the demand for shipping services. General market characteristics are usually known, while demand for specialist markets is usually unknown. An example of the general shipping market within Norwegian aquaculture is the transportation of harvest-ready salmon. The demand undoubtedly increased, as salmonid production volumes went up. The decline in production volume growth rate in the years since 2013 has when solely taking transport of harvest-ready salmonids into account, introduced more equilibrium between supply and demand. Dividing specialist markets into categories or sub-markets can help identify transport demand. Doing so can reveal specific demands and supply (i.e., transportation services) and systems adapted to the market demands.

Erichsen divides market information into two categories, *factual market data* and *market development prognosis* [32]. Factual or *real* market data can be accessed from official reports, e.g., national statistics bureaus, and specialized publications. In Norwegian aquaculture, specific statistics are reported to separate government and regulatory bodies. Farmers report production figures, or biomass figures, to the Norwegian Directorate of Fisheries (NDF) every month. These include production facilities in use, stock figures, number of smolt released, harvest figures, production losses, and more. Weekly reports also have to be submitted to the Norwegian Food Safety Authority (NFSA). These include sea temperature, number of lice, type of treatment, treatment duration, and use of cleanerfish [10]. Ship characteristics data can be found in databases such as *Sea-web*, databases provided by national maritime authorities, magazines, or online class registers. The data can provide insight into vessels used by competitors operating within the same market, or serve as *comparison ships* for new projects. "*We must evaluate previous constructions and continuously look for more efficient, more practicable, more reliable or cheaper solutions* [20]. By analyzing previous designs, i.e., capacities, performance, and economics, areas for improvement can be identified.

Statistics can be used as the basis for prognoses [32]. For years this was true for salmonid transportation demand in Norway, as production volumes steadily increased. This rather crude way of estimating future demand seems to no longer be valid as growth has slowed down. Concluding that the demand for salmon transportation systems has reached an equilibrium, as a consequence of production volumes reaching equilibrium is an equally crude use of statistics. Instead of basing forecasts on direct analysis of statistics, the underlying causes for demand development should be revealed [32]. Government regulation affects salmonid transportation demand, both concerning vessel design and sea production. Demand for Norwegian Atlantic salmon on the global market is high, as is reflected by the export value of the industry (income form salmonid export is growing despite the plateauing of production volumes). Solving or mitigating critical environmental challenges (e.g., salmon louse related issues) is likely to lead to an increase in production. Circumventing these challenges, e.g., by moving production to more exposed waters, is also expected to increase transportation demand.

The demand for salmonid transportation does have a limit, even if production volumes were to go up again. Demand may arise out of the need for new development or the need to maintain and replace existing developments [32]. Typical development of demand follows an S-shaped curve, as seen in Figure 2.5. Demand increases rapidly shortly after being introduced, followed by a period of growth. After some time demand reaches an equilibrium and, depending on the market, and for different reasons, decline.

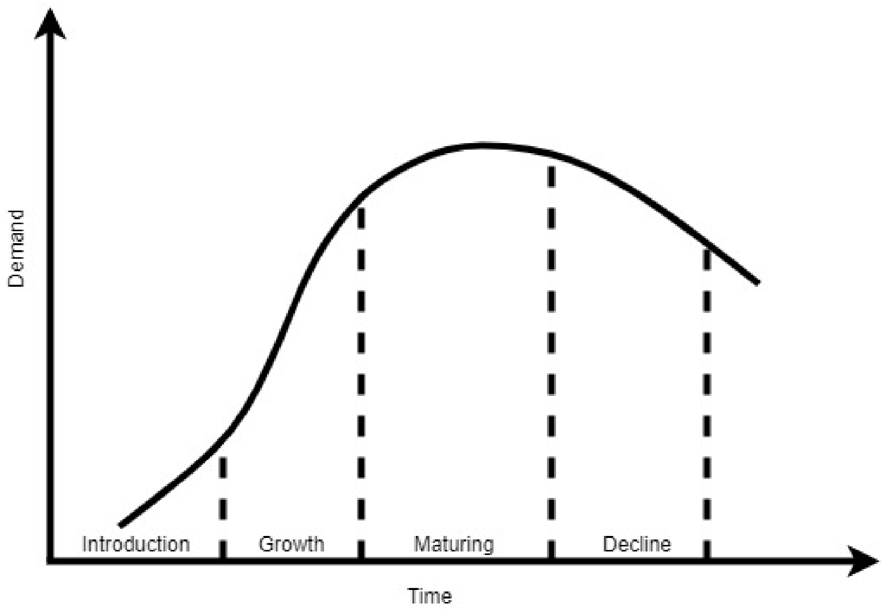


Figure 2.5: Typical development of demand over time [32].

Determining how far the transportation need is from satisfaction and where the current date is along the S-shaped curve has proven to be difficult within salmonid transportation. Many have, and still are, warning of overcapacity in the transportation market. A master thesis from 2016 found that supply surpassed demand in 2013 [33]. The creation of sub-markets can help explain why stagnation in demand within the salmonid transportation market has not occurred. If defined in a certain way, the development of these sub-markets can more easily be tracked through time. The historical development of sub-markets within the Norwegian salmon transport market can crudely have said to be: 1) transport market with the use of smaller LFCs using open-well technology (few of these remain today); 2) medium-sized LFCs with limited closed well technology (larger, more modern LFCs are rapidly replacing these); 3) Large LFCs with fully developed closed well technology (most newbuilds fall into this category); 4) demand for delousing operations (a large percentage of an LFC's operational profile).

3 The Norwegian aquaculture industry

This chapter describes the current situation in Norwegian Atlantic salmon farming, with a focus on transportation and the downstream value chain. First explained is the development of the industry's production volume and how and why regulations in modern times have affected the halt in production is explained first. Understanding the present situation, e.g., the scale of production sites (both current and near-future ones) or the established land logistics chains, is essential for understanding industry requirements. The current transport systems in use in the salmon value chain today are presented. The focus of this part of the chapter is the development of live fish carriers (LFCs) and how this vessel type operates within and affects the salmon value chain. In particular, the physical interfaces of the LFCs, i.e., the sea production cages and the on-shore processing facilities.

3.1 The development of salmon farming in Norway

While the farming of salmonids in Norway has roots back to the 1850s, the modern, industrialized industry in seawater started around 1960 (first with Rainbow trout, then Atlantic salmon in the late 1960s) [34]. In 1970 the first widely successful production cage design made its debut [35]. Figure 3.1 shows an example of the Grøntvedt cage [1]. In the 70s, the Norwegian government saw the need for regulation to control the development of the industry [36]. The policy centered around the idea of placing facilities in coastal communities to strengthen their economic basis, by awarding licenses. Larger companies showed interest, particularly oil companies. However, their entry into Norwegian aquaculture was blocked as the protectionist government now reserved the right to award licenses.

Figure 3.1: The Grøndtvedt cage design, somewhere outside Kristiansund 1972-73 [1].

In the 70s, the growth of the industry was explosive, with average production growth of more than 40 % in some years (1972-1975) and 70 % in 1981 (albeit production volumes were minuscule compared to today's) [36]. In 1985 a new law further elaborated on the question of who should be allowed into the industry, as well as production volume and growth. Despite considerable growth, many felt that it could have been larger, if not for confining regulations. Others, those most familiar with the industry, understood that the new industry competed with other societal interests over area and resources. Aquaculture had to mature into the Norwegian society. If the public tone on the beginning was positive towards the industry and its possibilities, it soon became focused on other aspects of it, such as disease, medicinal use, overproduction, and bankruptcy.

Hatcheries did not require a license to run; they only had to register [36]. Hatcheries produced vast numbers of smolt, and within two years, overproduction in hatcheries moved to the sea production cages. Between 1987 and 1989, production volumes more than doubled (from 56 000 tonnes to 118 000 tonnes), flooding the market. At the same time, aquaculture interest organizations had encouraged their members to hold back production. Some had done just that, but the whole industry with all members was held accountable. A joint effort of freeze storing unsold fish partially avoided widespread industry bankruptcy. Densely packed sea cages brought with other problems, as salmon tend to be susceptible to disease under such conditions. The use of medication increased steadily along with production volume (see Figure 3.2), and escaped fish posed a risk of spreading diseases and parasites to wild stocks [37].

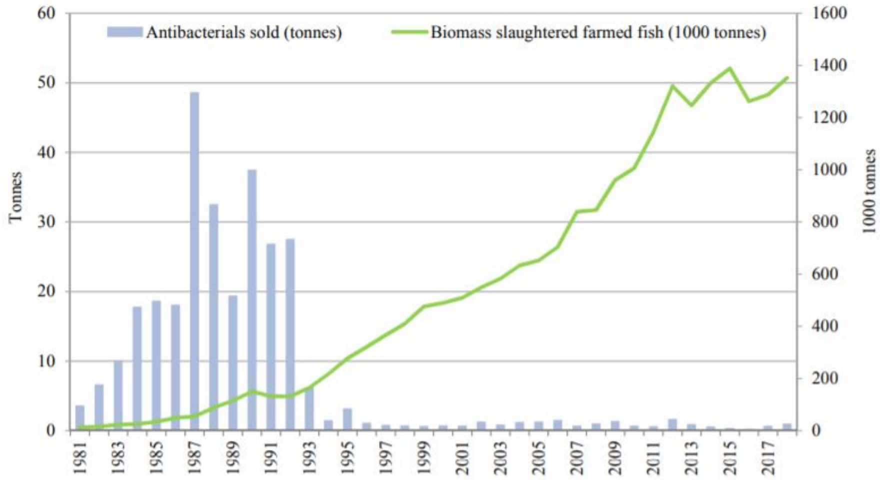


Figure 3.2: Sales figures for antibacterial products used in Norwegian fish aquaculture versus production volumes in the period 1981-2018 [37]

The effects of aquaculture on the surrounding environment (the sea) were more severe than the effects of traditional husbandry on land [36]. In the early 1990s, this realization provoked questions regarding the sustainability of aquaculture as an industry. As the production volumes grew, so did cash flows, and as the credit market became more liberal in the country, banks were more inclined to finance new facilities [1]. The liberalization had its cost. Issues related to diseases, algae blooms, and low prices due to overproduction put owners, without substantial equities, under challenging positions with creditors.

The market demand was well below the supply of Norwegian salmon in 1991. The policy of freeze storing, primarily funded by the government, assured pressured farmers a minimum price of salmon [1]. However, the set price created a false market as pressured farmers did not slow down production; they had to stem off creditors. A lack of lowered production volumes or sufficient market development, coupled with a sudden anti-dumping duty of 26 % on imported Norwegian salmon in the US, significant economic losses threatened farmers in the fall of 1991. Government financial intervention saved the banks, but the Fish Farmers Sales Organization (which through loans had funded the freeze strategy) went bankrupt in the fallout. So did many of the farmers. Companies with stronger equities seemed necessary if the industry was to move out of the crisis and evolve.

The government repealed the requirement of local affiliation for majority owners [1]. A restructuring of the industry led to the most significant change since the government had started awarding licenses on a regional basis (it had led to salmon farms established in the very south of Norway to the border with Russia). Licenses purchased from bankruptcy threatened farmers were inexpensive, and financially secure companies were able to grow considerably through acquisitions (SalMar AS started in 1991 after purchasing one license for a bankrupted combined production and processing facility). Ownership became more concentrated within fewer companies during the 1990s (70 companies contributed 80 % of the production volume in 1997, compared to several hundred before the 1991 crisis). Market development was essential as Norwegian production volumes doubled in the 1990s. Also, farmers in countries like Chile and Scotland were growing and competing for the same customers.

Many Norwegian companies had financed their acquisition growth through credit from the banks [1]. Licenses were attractive investments, and their prices increased dramatically throughout the 1990s. 2000 was an outstanding year profit-wise, but by 2001 sales prices were down, and a new wave of bankruptcies came in 2003 as farmers failed to manage their high capital costs [38]. Salmon as a consumable had become less of a luxury item due to high supply, and subsequently, price elasticity went down. Still, production kept going up in the following years. From 1992 to 2008 the production volume increased with around 600 % [1]. In the same period, the number of newly awarded licenses increased only by 23 %. A change from regulating production volumes based on feed quotas to the maximum permitted biomass (MPB) regulation in 2005 is estimated to have facilitated a 30 % increase in production volume.

Technology development has also played a significant part in the production volume increase. Sea cages went from small wooden structures inside the safe waters of fjords to more exposed waters using intricate mooring systems and high-quality plastic materials. The size of the production cages and sites has increased, causing significant environmental consequences from instances with escaped salmon. Revised regulations were introduced in the NYTEK regulation in 2011, in order to prevent escapes from sea production cages [39]. The regulation dictates owners of sea production sites, and suppliers of equipment and materials, to adhere to a standard of minimum quality (NS 9415:2009) [40]. As with the rest of the seafood industry in Norway, aquaculture has seen an increased degree of investments related to machinery/equipment and research and development [41]. The Development permits, initiated by the Norwegian government in 2015, led to a transfer of technology from the Norwegian petroleum industry. This transfer of offshore technology has made salmon farming possible at sites exposed to harsher weather conditions along the Norwegian coast (e.g., Salmar's "Ocean Farm 1" and Nordlaks' "Havfarm") [42].

Several government-funded programs have attempted to solve the sustainability issues in the industry. One example is the Development license program. The goal of the program was to facilitate the development of technology capable of solving environmental and area challenges in the industry, incentivized by awarding valuable farming licenses [43]. Another example is the Traffic light system, dividing the Norwegian coast into 13 production zones according to how the Salmon louse (*Lepeophtheirus salmonis*) spreads at sea [44]. The goal has been to identify areas for possible growth and necessary reduction in production based on Salmon louse infestation on wild salmon and trout, caused by salmonid farming. The government introduces or update regulations regularly, typically imposing stricter requirements for aquaculture technology, e.g., the change in the regulation on transportation of aquaculture animals, requiring treatment of transport water [45].

Research and development efforts on salmon biology have proven essential for the development of the industry. Breeding programs have resulted in salmonids' more rapid growth, better immune system, robust health, and feed utilization [1]. Still, the industry has never been able to evade the issue of disease and parasites. Issues related to escapes and the Salmon louse is arguably the main reasons the Norwegian government introduced new regulations in 2013. The regulation refined requirements to acquire an aquaculture farming license. [46].

3.2 Development of salmon transportation in Norway

The ship segment of the industry has followed the development of the industry throughout the years. As production sites moved further from shore larger and more specialized vessels were needed. As with the rest of the industry high profits, regulatory demands, demand for more efficient production and the need to handle biological challenges has driven up investments in later years [41]. This is not an exception within the salmonid transport segment.

In the early days of the industry, salmon was commonly slaughtered at the production sites, subsequently transported to the close-by shore in small boats [47]. Hauling entire cages with harvest fish has also been common practice (this is still carried out today, but has been highly advised against for overt disease spread and escape risks [48]). Tank trucks, helicopters, and ships of different categories are systems in use for salmon transport [49]. Due to small scale production at on-shore facilities, and shorter transport distances, the need for specialized ships was not a necessity in the early days of industrialization. For a truck to overcome the challenge of not being amphibious, a ferry could be utilized (see Figure 3.3) [50]. As the industry scaled up, both harvest volumes and distances from net cages to shore increased. New methods for transporting large volumes were needed to meet transportation demands.

Figure 3.3: Smolt delivery by truck to a on-growing site in northern Trøndelag [50].

Wellboats are vessels meant for transporting live fish in its cargo hold (well) [49]. Before they became common in salmonid aquaculture, their technology was used for decades in fisheries in Norway. Particularly in active fisheries (such as demersal seining and purse seining), where they transported, among other species, live saithe (*Pollachius virens*) from the fishing grounds [51]. In the early 2000s, it became common for fishing vessels in the Atlantic cod (*Gadus morhua*) fisheries to deliver live fish for storage (capture-based aquaculture) [52]. The largest LFC company today, Sølvtrans AS, purchased their first LFC in 1986 [53]. It was a reconstructed freighter, originally built in 1957, and had a cargo volume of 237 m^3. Compared to the tank volume of trucks (> 8 m^3) and helicopters (> 1 m^3), ships could carry substantial amounts of salmon [49].

Tank volume is the most commonly used metric to determine an LFC's cargo capacity. In this thesis, cargo volume and refrigerated seawater (RSW) volume (both measured in cubic meters) are used interchangeably. The cargo volume of Sølvtrans' first LFC might have been large at the time it was introduced in 1986, but compared to the vessels used today, it is minuscule. The development of LFC cargo capacity can be seen in Figures 3.4 and 3.5. The largest vessel currently in service is the Sølvtrans owned vessel "Ronja Storm", a 116 m long vessel capable of transporting 1200 tonnes of salmon [6]. Data for the figures originate from news articles, marintetraffic.com, order lists for Norwegian shipyards, and the Norwegian Maritime Authority's ship register. Tracking the origin of LFCs in use today is somewhat of a challenge. Most vessels before 1994-95 are refitted vessels, previously used for other purposes, or reconstructed LFCs. One example is the Norwegian vessel "Hauglaks" (previously an LFC now operating with stun-and-bleed technology). Most LFCs in use in the world today have Norwegian ownership, in addition to being of Norwegian origin. Figure 3.5 shows the cargo capacity currently in use, flying under the Norwegian flag. The left axis shows the accumulated cargo capacity, while the right axis indicates yearly cargo capacity entering the market. It is assumed that vessels with planned delivery after 2020 are to have Norwegian flag as Norwegian shipowners have ordered them. The reason for the large increase in both the number of vessels and size of individual vessels can be understood in the context of increased production volumes, not just in Norway but in other countries that Norwegian LFC owners operate. However, most new vessels enter the Norwegian market, where production volumes have stagnated since 2012. In Norway, most cargo capacity has entered the market in the years after 2012.

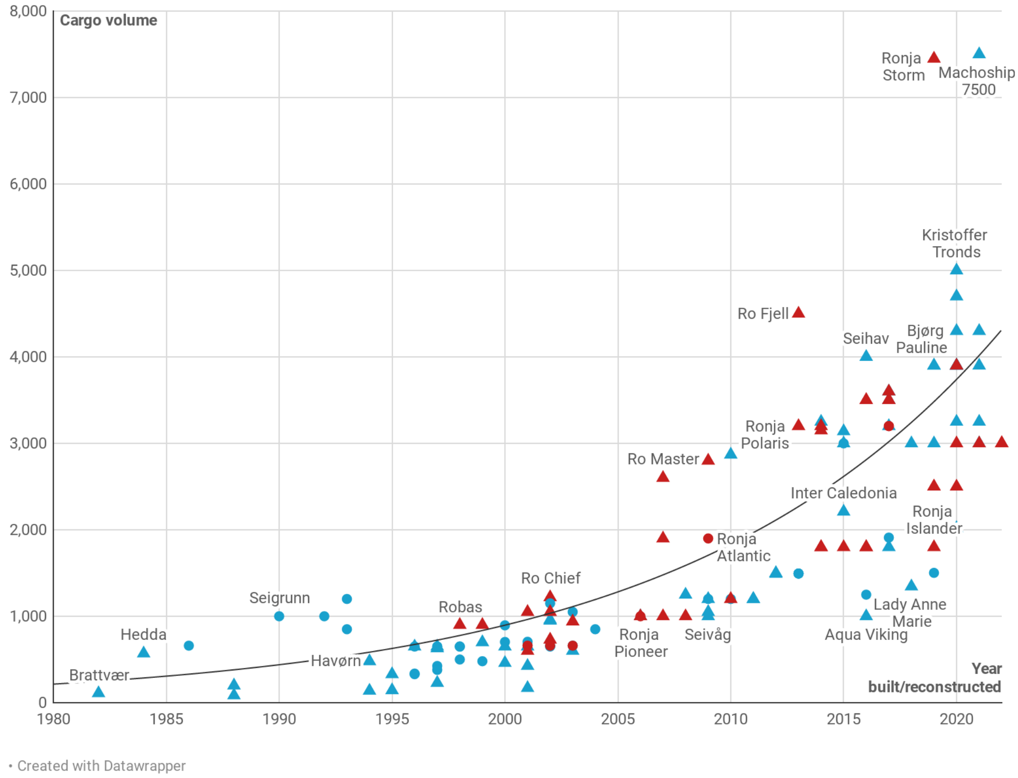


Figure 3.4: Selection of LFCs in operation today with their respective cargo volume [m^3] and build year/year of reconstruction. Red dots are vessels owned by the two largest LFC companies in the world (Sølvtrans AS and Rostein AS). Triangles represent LFCs with Norwegian flag, circles represent vessels flying under other flags.

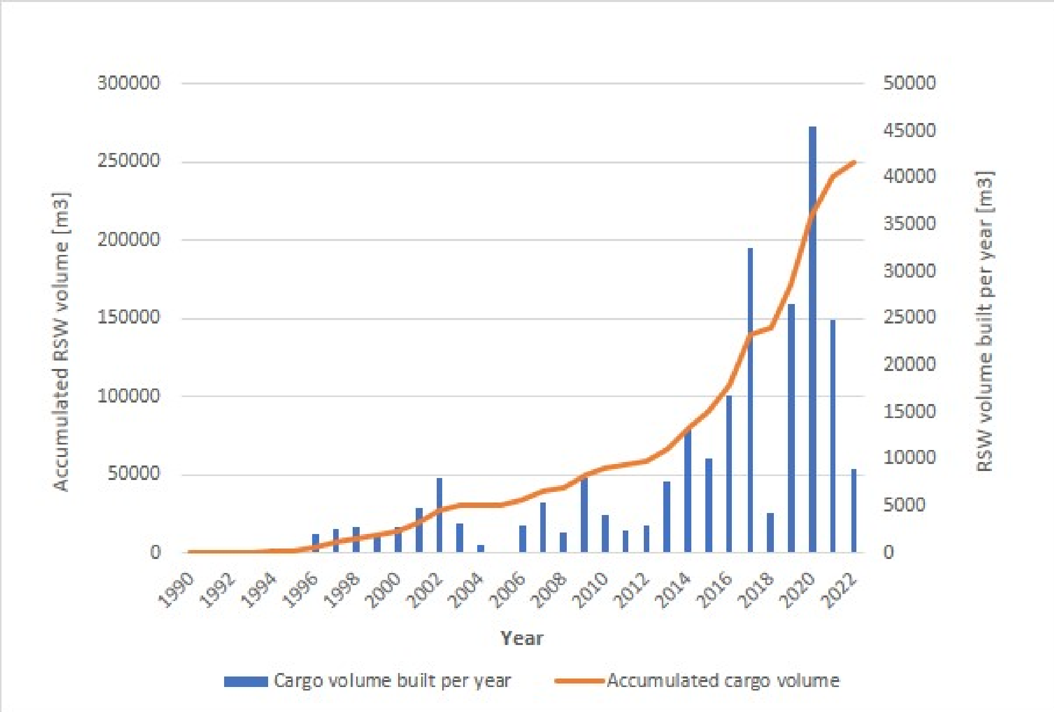


Figure 3.5: Accumulated and year of entry for LFC cargo volume [m^3] in use and expected to enter the Norwegian market as of Feb 2020.

The first vessels, purposely built for transporting salmonids, were built in the early 1990s. As the crisis of 1991, and the following liberalization of the industry, had allowed companies with strong equities to enter the market, production volumes increased, and farmers saw the need for more efficient transportation of harvested fish. Around 1990, the first LFC produced by what became a powerhouse within LFC newbuilds, Aas Mekaniske Verksted AS, entered the market. The company built more than 15 LFCs from 1990 to 2000 [54]. In the mid-1990s, a standard LFC had around 3-400 m^3 cargo volume. By today's welfare standards, a 400 m^3 LFC would be able to carry a maximum of 60-70 tonnes. They operated basically by the same principle as earlier wellboats used in fisheries; live fish are transported in the LFC's wells from either a smolt facility or production cages. The salmon would be supplied with oxygenated water by a continuous flow of seawater through the well, using a *open-well* system (see Figure 3.6). In an open-well system, seawater will flow through the well when the vessel moves through the water by opening valves fore and aft of the well. Circulation pumps provide flow in stationary situations. The method also removes waste products (e.g., salmon fecal matter and carbon dioxide).

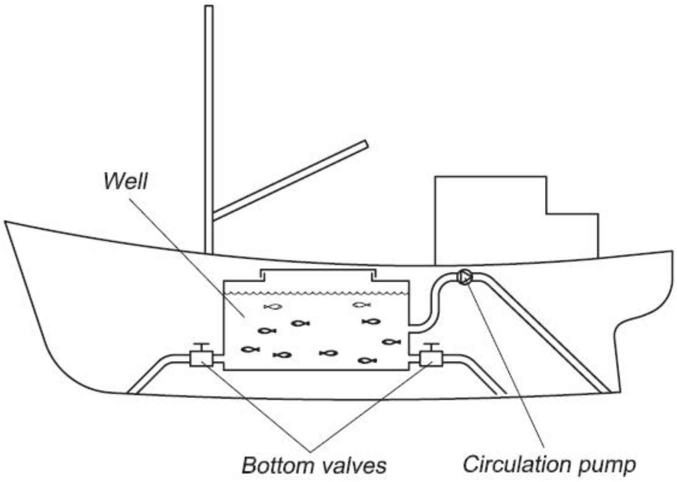


Figure 3.6: Schematic of a LFC using a open well system [49].

The size of the vessels steadily increased, and companies like Sølvtrans saw opportunities in other aquaculture countries [55]. The company's CEO moved two newly acquired LFCs to operate in Scottish waters in 1996. In May 1998, the viral disease Infectious salmon anemia (ISA) appeared in a Scottish salmon farm [56]. The virus causing the viral disease (ISAV) was subsequently spread to other farms throughout Scotland in a sporadic manner. Researchers concluded that it was the movement of wellboats, through shipping of live fish and visits at on-growing sites for harvest collection that had spread the ISA virus between Scottish salmon farms in 98-99. The use of LFCs was temporarily banned in the country, to prevent the disease from becoming endemic in Scotland as it had in Norway (ISA first appeared in Norway in 1984). The most severe risks of ISAV transmission was associated with the use of wating-cages near production sites [57]. The LFCs also posed a significant risk as they had open valves during transport. Researchers recommended the use of closed valves during transport. Furthermore, larger vessels would imply fewer transport runs, subsequently decreasing the risk.

The main issue with using closed valves is the lack of supply of oxygen and removal of waste products (the build-up of CO_2, and ammonia are particularly problematic due to the substance's toxicity for fish [58]). With experiences from operating in Scotland, Sølvtrans AS' CEO, together with Aasmek, built the first LFC with *closed-well* technology in 2001 [55]. Three vessels with a cargo capacity of 600 m^3, at a total value of NOK 150 million was ordered. They all incorporated closed-well systems and new technology for unloading the fish without emptying the wells (sliding bulkheads) [59]. Re-oxygenation of fish tanks was a familiar technology used for truck transportation [49]. Also, chilling the well water with the use of an RSW system could lower the salmons' metabolism, which in turn delays the deterioration time of the transport water [60]. Fisheries had used RSW systems for several years by the early 2000s. Issues related to closed systems were still present. There were no systems in place that fully removed waste products (CO_2 and nitrogen compounds) [61]. Cleaning and disinfecting the vessel was an issue before LFCs with closed-well systems emerged. Both internal (including inside tubes, canals, and vacuum chambers) and external surfaces have to be cleaned (removal of larger organic and inorganic material) and disinfected (killing pathogens). With the largest LFCs exceeding 1100 m^3 by 2002, the risk of losing the entire cargo due to the failure of e.g., the treatment systems onboard closed LFCs now meant economic losses in millions of NOK.

There were few studies available at in the early 200s, regarding the use of LFCs with closed systems. With the introduction of closed transport and the question of how LFCs were contributing to spreading disease led to projects and studies in the mid to late 2000s [61], [58]. Welfare challenges for salmon in closed systems were also issues that drew more focus from the public [60]. In the same period, LFC's cargo capacities continued to grow. By the end of 2010, five vessels had a cargo capacity of 1900 m^3 or more. The largest, "Bjørg Pauline" ("Inter Nord" today) had a cargo capacity of more than 2800 m^3. The vessels could now transport 3-400 tonnes of salmon. As mentioned in Section 3.1, production sites had grown in size, and there were fewer and larger production plants to process the harvested fish. Production of salmon had been going up at a rapid pace, and increased transport capacity and modern vessels were in demand.

In 2008, the total production of salmon went down for the first time since the beginning of the century [62]. An attributing factor was arguably increasing challenges with disease and parasites. There had been an increase in cases of ISA (17 in 2008 versus 7 in 2007) and Pancreas disease (PD) (108 in 2008 versus 98 and 58 in 2007 and 2006, respectively) [63]. PD, along with Heart and skeletal muscle inflammation (HSMI), were the most significant contributors to the death of on-growing fish. PD and HSMI are examples of diseases that severely weaken the fish [9]. The operations associated with transporting live salmon weakened by disease inflict a severe strain on the fish. Live transportation of disease-weakened fish is a growing welfare concern.

Another issue that was becoming a greater challenge in 2008-09 was that the Salmon louse in some areas had developed resistance towards certain types of chemicals (e.g., active substances added to feed). The situation in 2008 was significantly deteriorated, with higher numbers of lice per fish reported compared to previous years [64],[65]. Resistance became widespread, and new medicines or methods were necessary. LFCs were increasingly using hydrogen peroxide (H_2O_2) from 2009 in combatting both Salmon louse and Amoebic gill disease (AGD) [66]. Salmon louse will develop resistance towards H_2O_2 over time [67]. In later years the use of H_2O_2 has decreased significantly, replaced by methods such as mechanical and thermal delousing [10]. Specialized delousing vessels do exist, but many LFCs have incorporated the mechanical and thermal delousing systems, adding them to their service portfolio.

A limited number but influential people have pushed the development of LFCs through the years. Companies with "best practice" mentalities have sought to meet the needs and requirements of their customers, the salmon farmers, before regulation demanded it. Events, such as the ISA epidemic in Scotland in 1998-99, highlighted the issue of LFCs as a source of disease spreading. Without permission to operate in an important market, Sølvtrans AS introduced the first LFC with a functional closed-well system. Investments within the vessel segment (LFCs, stun-and-bleed vessels, and service vessels) of the industry has been substantial in recent years [68]. The main drivers are stricter regulations related to Salmon louse, increased frequency of treatment, resistance towards chemicals, and a move towards mechanical delousing. Older LFCs today are sold to or used in other salmonid farming nations, such as Chile, Canada, and the UK. Some are still operating in Norway, servicing as smolt and cleanerfish transport vessels.

3.3 Modern-day harvesting and production

3.3.1 Production cycle

The production cycle of farmed Atlantic salmon typically follows a cycle like the one seen in Figure 3.7. Carefully selected broodstock salmon provide roe and sperm between November and March [69]. Onshore hatcheries rear the salmon in the first 10 to 16 months of the cycle. LFCs transfer the smolt out to production sites after the salmon reach a preferable size, and have successfully gone through the smoltification process. Salmon are anadromous and have to adapt to seawater. The smolts are released into the sea mainly during two periods; in the spring (mainly between March and June) and in the fall (mainly between July and October) [70]. The growth phase in the sea lasts between 12 and 24 months [69]. At the end of the cycle, LFCs or SBV transport the salmon to a slaughterhouse for processing.

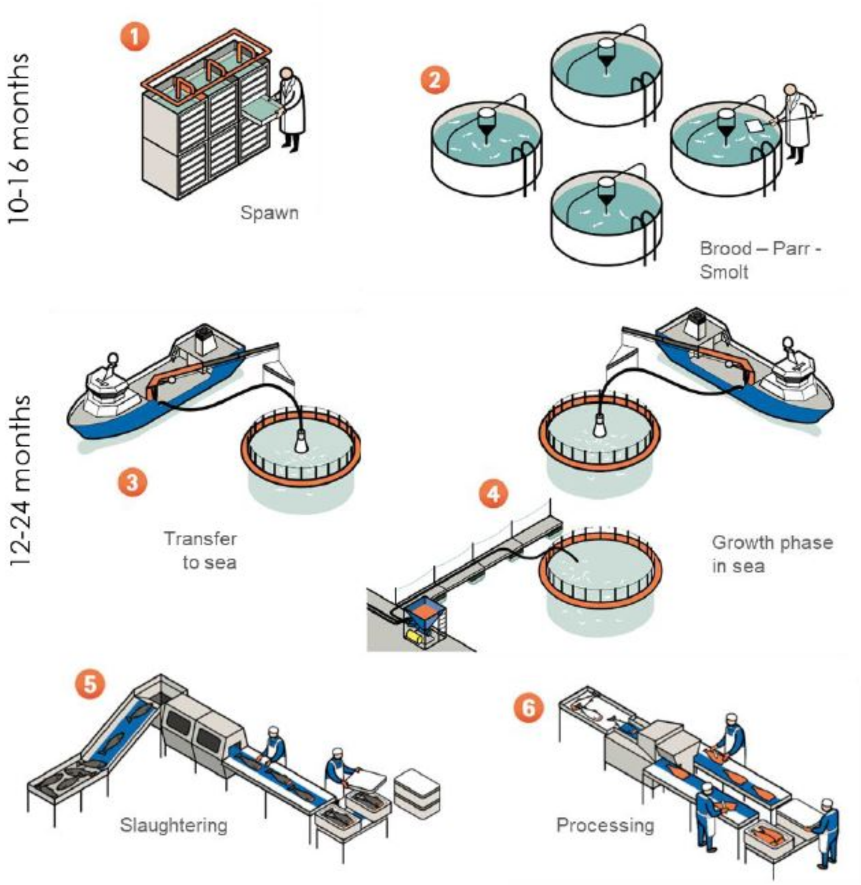


Figure 3.7: Production cycle of farmed Atlantic salmon [69].

As production has increased in the past ten years, so has the number of individual fish deaths, as seen in Figure 3.8. The figure only includes the amount of individual salmon reported as lost during sea phase production due to death [71]. Other production loss causes, like fish discarded during production, escapes, and other causes, have not been included. In 2019 alone, causes other than death at sea contributed to a loss of approximately 5 million individual salmon.

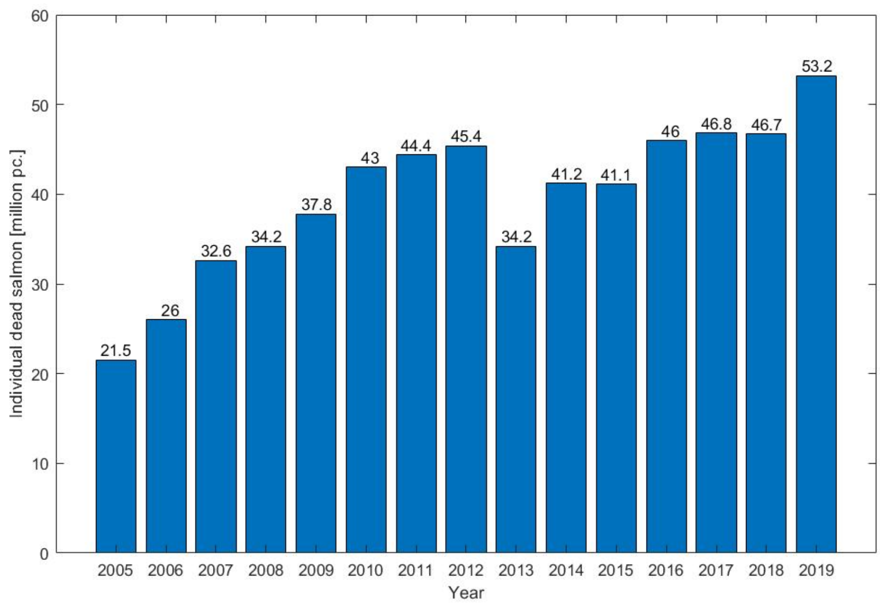


Figure 3.8: Individual salmon deaths in the sea phase in Norway from 2009 to 2019 [71].

3.3.2 Slaughterhouses

The number of or Norwegian slaughterhouses has significantly decreased in the last 30 years (from close to 250 to approximately 40 facilities) [2]. The reduction in numbers is not due to less activity but to a restructuring of facilities across the industry. Slaughterhouses are growing in size and have increased their delivery capacity or throughput considerably. Figure 3.9 shows the location of every processing facility that reported having processed salmon in 2018 (see Appendix A for a complete list of facilities) [2]. Most slaughterhouses have shift (a 7.5-hour workday) capacities smaller than 100 tonnes (21 by numbers). Smaller slaughterhouses (40-95 tonnes) are common in the north of Norway. Only five facilities north of Trøndelag county report on shift capacities of more than 150 tonnes. Two of three facilities with shift capacities above 300 tonnes are situated around the islands Frøya and Hitra, in Trøndelag county (owned by Salmar AS and Lerøy Midt AS). Together with Mowi ASA' slaughterhouse on Hitra, these three slaughterhouses processed 22.3 % of the total production volume in 2018 (285 500 tonnes). Approximately half of all slaughterhouses (20 by numbers) are situated south of the Frøya/Hitra cluster and processed 38 % of total production volume in 2018 (488 950 tonnes). Ten of these reported having shift capacities equal to or above 100 tonnes.

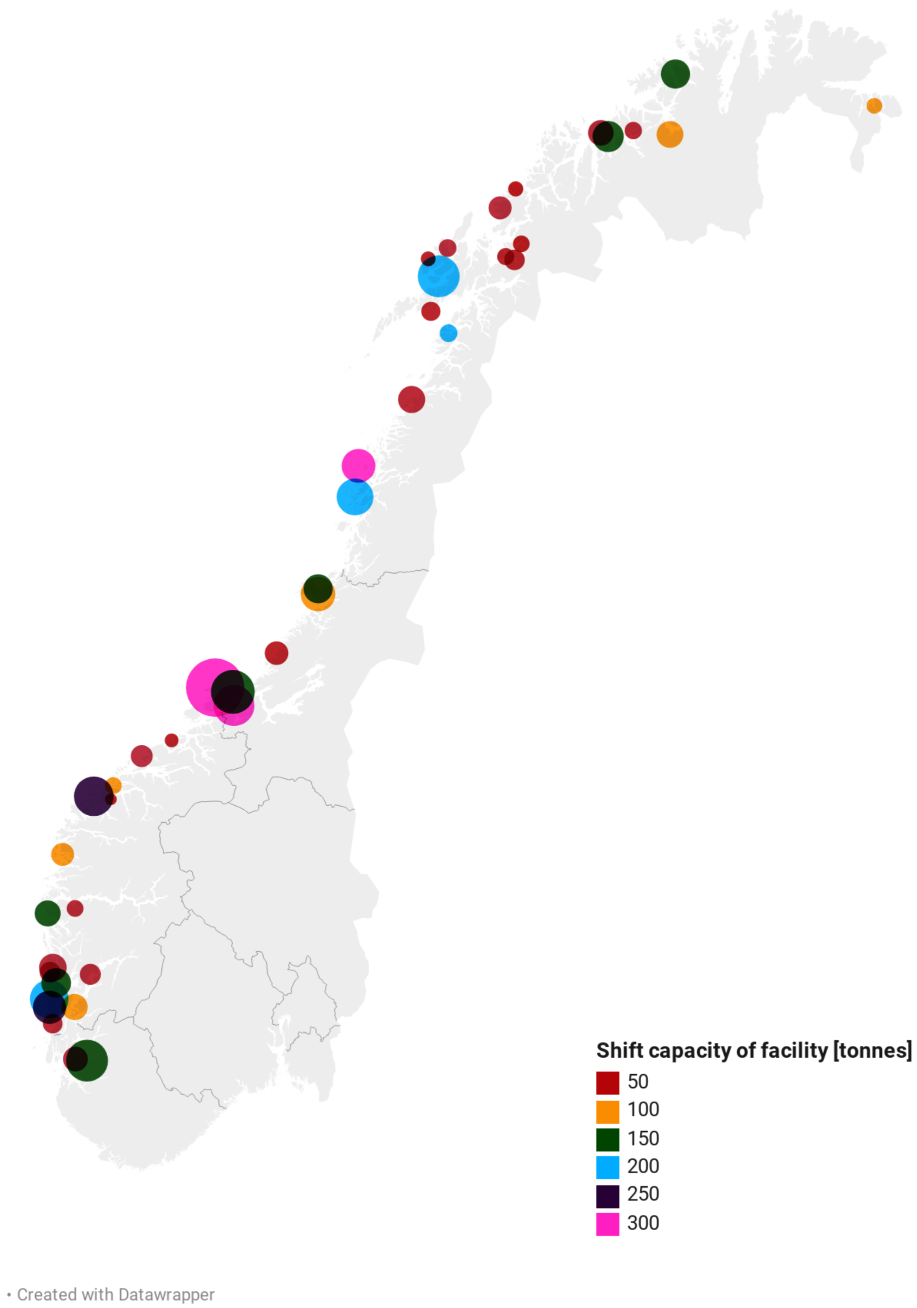


Figure 3.9: Facilities that reported processing Atlantic salmon and Rainbow trout in 2018. Size of circle indicates relative production volume from each facility. Color indicates the capacity per shift in tonnes. The figure is based on [2]

As is the case for many industries, the level of automation and efficiency has increased considerably [72], [73]. Processing of salmon is expensive in a high-cost country like Norway, not able to compete with countries like China [74] and the EU [75]. Therefore, exported products are mainly in the form of slaughtered, whole salmon, also known as Head-on-gutted (HOG). Close to 85 % of all salmon products exported in 2018 was in the form of fresh or frozen HOG [76].

Figure 3.10 depicts the processes in the production line of a modern-day slaughterhouse [77]. The harvesting starts with starving the fish while still in production cages[78]. Starvation has several reasons: It increases the salmons' acute stress resistance. Moreover, it reduces the fish's need for oxygen, added to the water during live transportation [79]. Finally, the starved salmon does not produce waste on empty stomachs, and the hygiene during gutting is improved. LFCs harvest the salmon at sea production sites and deliver the salmon to the slaughterhouse. Usually, the LFC unloads the salmon into waiting-cages situated in close vicinity to the slaughterhouse.

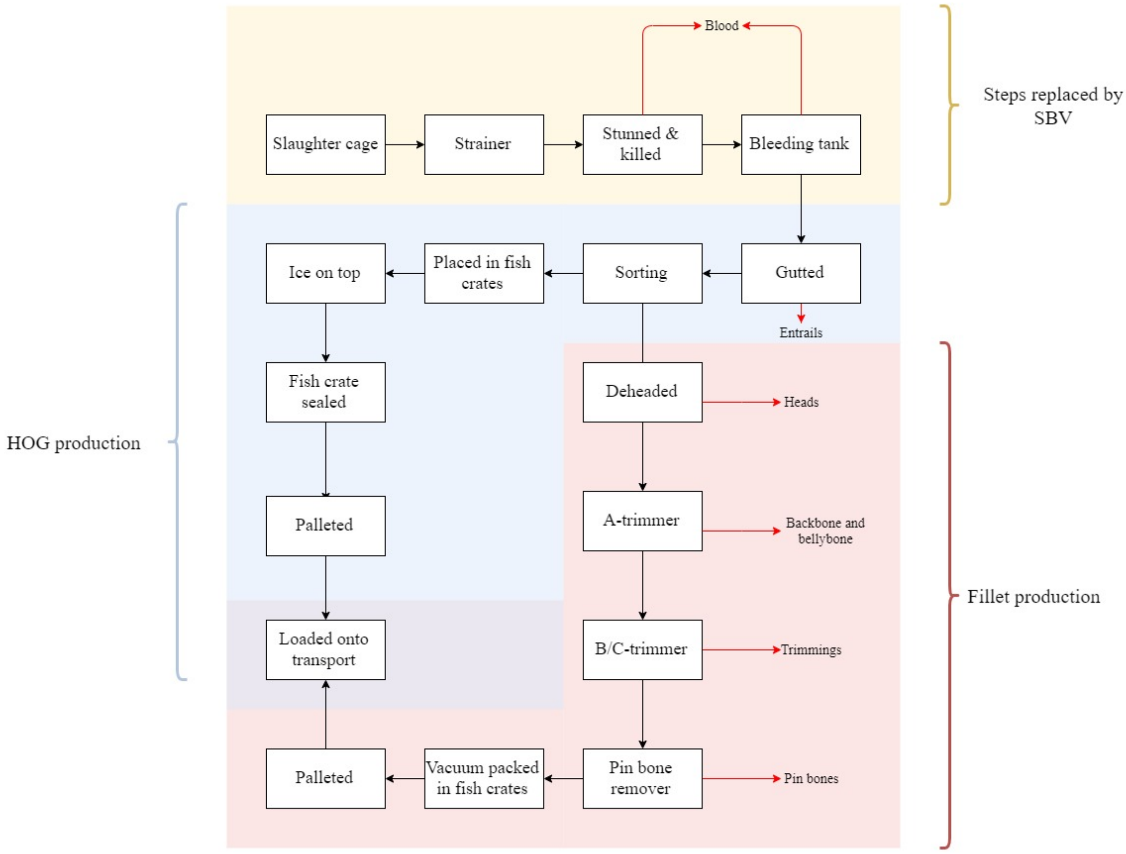


Figure 3.10: Example of a traditional slaughterhouse production line. Yellow area represents steps eliminated by the use of stun-and-bleed vessels (SBVs), blue a HOG production line, and red a fillet production line. Red arrows indicate rest raw materials as a result of processing. Inspiration for the figure comes from the video "Fra smolt til ferdig slaktet laks - SinkabergHansen AS" [77].

According to regulation, salmon can be stored in waiting-cages for up to six days [80]. Before the processing onshore begins, the salmon is transferred to a slaughter-cage (at some facilities waiting cages are used directly for this purpose, and many use these terms interchangeably). A crowding net gradually diminishes the space within the slaughtering cage is gradually diminished. This "crowding" operation is necessary to pump the salmon into the facility effectively. Typically a vacuum pump pumps the salmon from the slaughtering cage into the facility. The handling of salmon by crowding and pumping it is a considerable concern for the welfare of the fish [72]. The handling causes stress and depletes the salmons' energy storage. Rough handling during crowding or sharp edges within the pumping system can damage the fish, subsequently lowering the quality of the salmon. Some facilities require or have the opportunity of receiving the salmon directly from LFCs [61]. Direct unloading is a requirement for salmon identified with PD (although the Norwegian Food and Safety Authority can make exceptions) [11] and in cases when the environmental conditions in the waiting-cages are particularly stressful for the fish [80]. An example of a stressful condition is when the seawater temperature exceeds the salmons' tolerance.

When entering the slaughterhouse, the salmon passes over a strainer, separating the fish from the seawater. Regulation requires the salmon to be entirely unconscious before it dies [81]. Two main methods used for stunning: percussion and electrical stunning [72]. Percussion stunning involves the impact of a bolt to the salmon's head, causing a shock wave in the fish' brain, and a subsequent concussion. With the use of electricity, the entire salmon is exposed to an electric current, rendering the salmon unconscious as the current passes through the brain. Some slaughterhouses utilize "behavioral tubs" as a part of percussion systems. These tubs are ahead of the percussion system in the processing line. Water at high velocity flows into the tub, stimulating the salmon to swim towards the current and into slots where the percussion bolt stuns the fish. A bleeder machine kills the salmon by cutting the fish' main blood vessel in front of the heart.

Salmon is transferred to a bleeding tank, draining the blood from the fish. A combined bleeder tank and cooling tank, using refrigerated seawater (RSW), can be used to start the process of chilling the fish. The salmon has to have a temperature of no more than 4°C before packaging, preferably 0°C before packaged in ice [82]. International transport regulation demand that fresh fish never reach a temperature above 2°C [83]. Chilling can be a challenge, especially during summer, when salmon core temperature can reach be 15-17°C [82]. Cooling is an energy-demanding and costly process. Furthermore, time-consuming chilling efforts can lead to salmon entering *Rigor mortis* (postmortem rigidity), after as little as 3 hours after death. Post-rigor fish are more difficult to process as the fish becomes stiff and inflexible, an issue for many processing machines [84]. Also, pre-rigor processed salmon is considered as a product of higher quality [47]. Ten percent of the process water from the bleeder tank is removed every hour to avoid bacterial contamination [85]. However, recirculated water in these tanks, due to energy consumption, poses considerable risk of contamination.

The aforementioned stages in the slaughterhouse processing line are those that are considered replaceable by stun-and-bleed vessels (SBVs). Incorporation of the types of systems used in an on-shore slaughterhouse is discussed in Chapter 6. The rest of the process line in a slaughterhouse ensures that the salmon is gutted and cleaned, sorted according to quality grade, either further processed (red area in Figure 3.10) or placed in a fish crate with ice. Crates with salmon are palleted and places in semitrailers. A typical semitrailer transports 19 tonnes of HOG [86]. A slaughterhouse with a 300-tonne shift capacity thereby needs 16 semitrailers per shift.

3.3.3 Export markets and current transport situation

Norway is the largest exporter of farmed Atlantic salmon in the world by far [69]. In 2018 almost all salmon were exported as fresh or frozen HOG [87]. Figure 3.11 shows the 2018 distribution of exported products [76]. The percentage of exported frozen salmon has steadily decreased the last decade, as seen in Figure 3.12. A small amount of salmon is processed further than HOG, and most of this is either fresh or frozen fillet (10 and 5 %, respectively, in 2018). The processing industry is labor-intensive, and Norwegian labor costs are high [75]. Norwegian hourly labor costs were 55 % higher than EU labor costs in 2013. Subsequently, some of Norway's largest export markets are not primary consumers of salmon but importers of Norwegian salmon for further processing. Poland exports approximately two-thirds of the same salmon it has imported to other countries, mainly Germany [88].

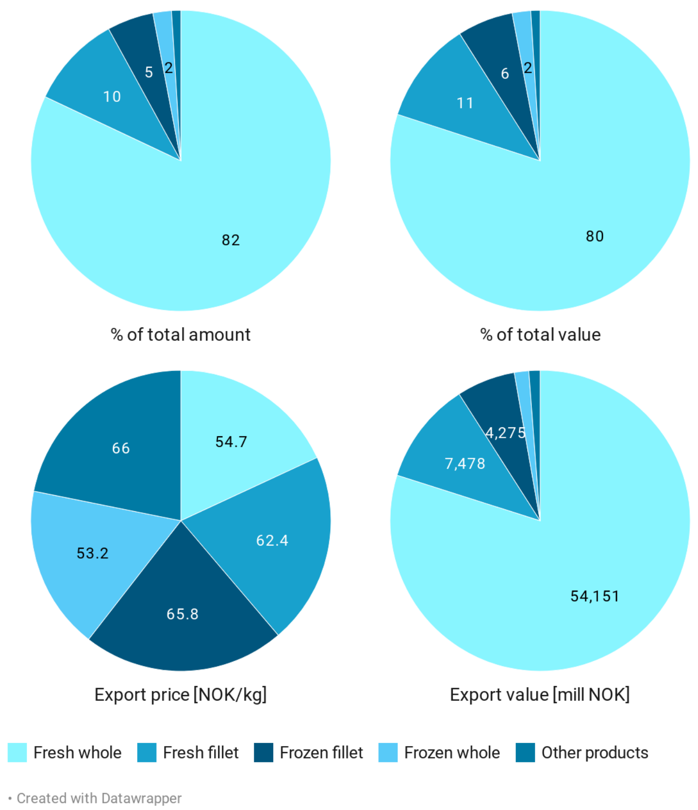


Figure 3.11: Atlantic salmon products exported in 2018 [76].

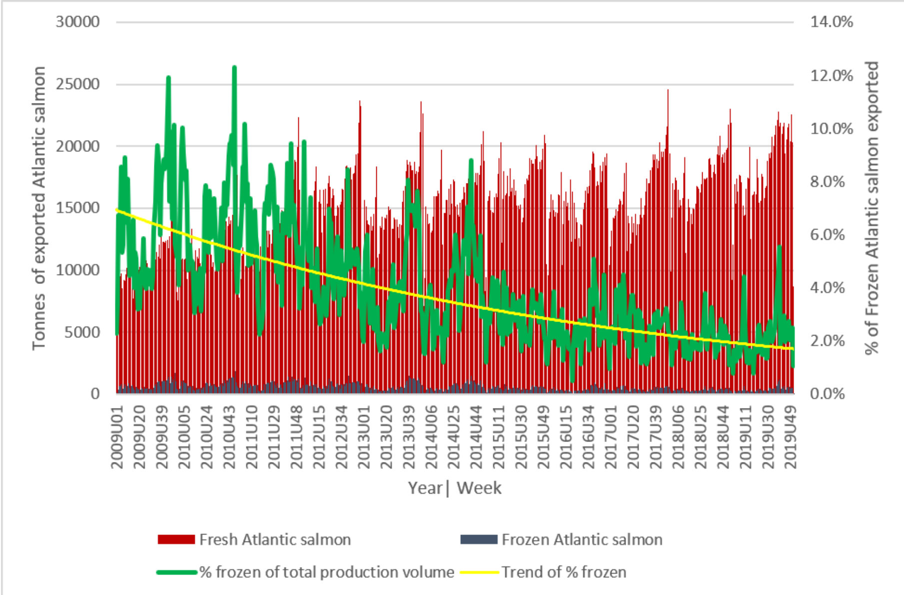


Figure 3.12: Weekly export of fresh and frozen Atlantic salmon in tonnes in the period 2009-2019 [76].

In Figure 3.13 export figures collected by the Norwegian Seafood Council and published by the Norwegian Directorate of Fisheries shows the distribution of exported salmon by country from 2012 to 2017 [89]. The three largest markets France, Poland, and Denmark, import approximately a third of all salmon produced in Norway. The EU as whole imports more than 70 % of Norwegian salmon, Japan 4-6 %, and the US less than five percent. Russia was one of the largest markets until recently. Imports to Russia decreased dramatically when the country partially closed its borders in 2014, as a response to western sanctions [90]. In 2018 3.4 and 2.5 % of total salmon exports went to Japan and South Korea, respectively [87].

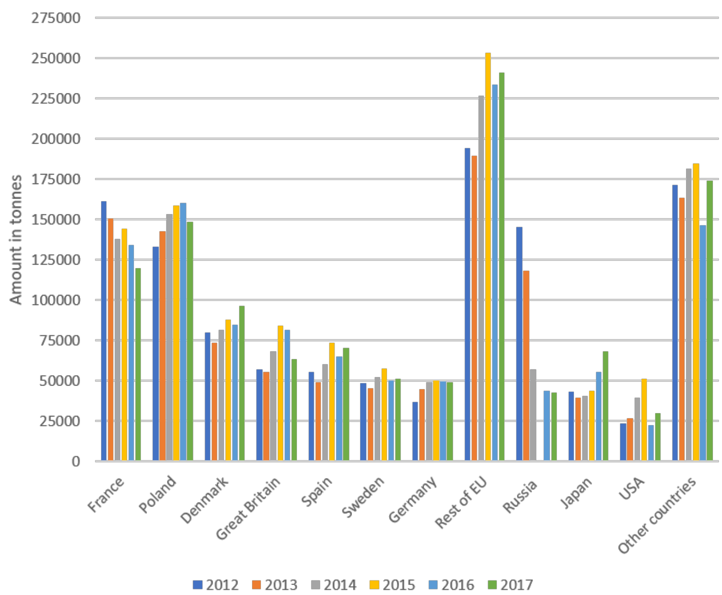


Figure 3.13: Amount transported to Norwegian export markets in the period 2012-2017 [89].

Norway competes with other salmon farming nations such as Chile, Australia & New Zealand and Canada, although each region has historically focused on developing nearby markets [69]. An exemption to this is the Asian market, where virtually no salmon farming exists. This market is shared by most international salmon producing nations. In the EU, Norway's main export market, around 70 % of salmon sold in retail (home consumption), while the rest is sold to hotels, restaurants and cafés (HORECA). Approximately 70 % of the salmon sold in EU was sold fresh. The market demands fresh salmon, and as salmon is a highly perishable product, efficient transport modes are needed to deliver large quantities of salmon to customers [86]. Time is a an essential element for retaining quality but so are the harvest processes and systems in use before exporting the salmon out of the country.

Following recent changes in Norwegian salmon farming, there are currently three vessel types in use for transporting salmon from production sites to slaughterhouses. These are Live Fish Carriers (LFCs), stun-and-bleed vessels (SBVs), and the ship "Norwegian Gannet" (the only ship currently killing and gutting salmon onboard and delivering overseas). Figure 3.14 shows how salmon moves from Norwegian sea production cages to secondary overseas processing facilities. Each step in the figure marks a vital processing step using the three transportation modes. The salmon are killed in the step "Stunned & bled". Both SBVs and "Norwegian Gannet" perform this step at the very onset of the harvesting process, while when using LFCs, this step takes place long after completing the transportation phase.

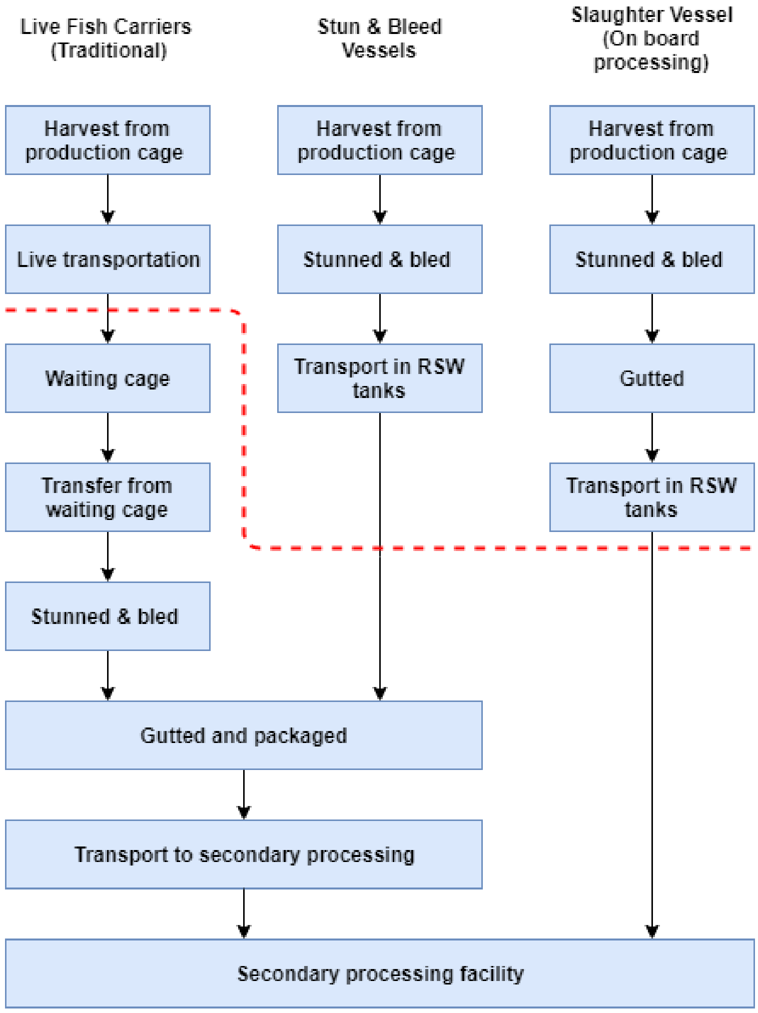


Figure 3.14: Flow chart showing how Norwegian salmon moves from production cage to secondary processing plants outside Norway. The red dotted line indicates when the salmon leaves the vessels.

The "Norwegian Gannet" concept, promised to alleviate the pressure on Norwegian roads from semitrailers by delivering slaughtered salmon directly to a packaging terminal in Hirtshals, Denmark [91]. The owners of the project insisted that the freshness of the product would be better than salmon traditionally slaughtered in Norway. The salmon would be killed and slaughtered shortly after harvest and stored in RSW tanks at a temperature of -0.5°C. The result being an up to 7 days longer shelf-life than for salmon slaughtered in and transported by truck from Norway. Political intervention seems to have terminated the owners' ambitions of transporting around ten percent of Norway's yearly production volume. Industry stakeholders feared that the project was a threat to the reputation of Norwegian farmed salmon [92]. Salmon of lower quality, with visible wounds or deformities, must be sorted out and corrected before being distributed for human consumption [93]. A lack of the word *domestic* in the first sentence of §17, in the quality regulation, opened for interpreting that sorting could be done, e.g., underway at sea. In April 2019, authorities added the word "domestic" to the sentence. As of now, the future of the vessel type is highly uncertain. "Norwegian Gannet" operates with a time-limited exemption from the regulation [94].

Like "Norwegian Gannet", SBVs kill the salmon shortly after loading it onboard.

However, the system delivers salmon to on-shore processing facilities in Norway. As of now, these systems do not go further in processing than bleeding the salmon. Onboard RSW tanks chill the fish before directly delivering it to shore. A more detailed description of the SBV concept is found in Chapter 6. To be able to distinguish advantages and drawbacks with SBVs calls for a closer look at the traditional salmon transportation system, the LFC.

3.4 Live fish carriers (LFCs) in the value chain

3.4.1 LFC logistics

In the traditional harvest process, salmon are handled alive at least two times: Once during loading from the production cage and once during unloading at a slaughterhouse. Without direct unloading, using waiting-cages, three handling operations are necessary. All handling impacts the stress level of fish [95]. The final crowding and pumping step from waiting-cage to facility typically increase stress, significantly decreasing the pre-rigor time [82]. Figure 3.15 shows the development of stress levels in salmon during a harvest process. During the transport itself, the salmon becomes calmer and replenish its energy storage [58].

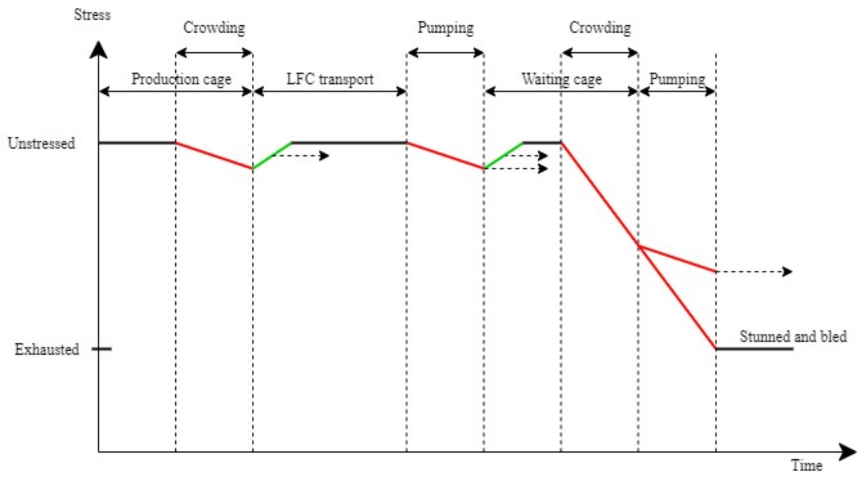


Figure 3.15: Stress level of salmon during different handling operations [82].

Waiting-cages are used for several purposes today [79]. The cages allow the LFCs to deliver their cargo without having to wait for production to start on land, and they contribute to calming down the salmon after transport. By utilizing a waiting-cage, the slaughterhouse can control the flow of salmon into the facility. Therefore, waiting-cages introduce a logistical advantage. In some cases, when using LFCs with refrigerated water in a closed circuit, the salmon can not be released into slaughtering cages [96], [61]. The reason is the abrupt temperature change, which is stressful for the fish.

Waiting-cages do not have to abide by the Maximum stocking density (MSD) allowed in production cages [80]. A 2014 guide document, from the Norwegian Food Safety Authority (NFSA), concerning fish welfare at slaughterhouses for aquaculture animals, states that: "*The requirements for maximum stocking density in slaughter cages are the same as for ordinary farms.*" [97]. The same document continues: "*In* *addition, §46 of the Aquaculture Operations Regulation* (Akvakulturdriftforskriften) *states that the density shall not exceed 25 kg/m³. The company must not have a higher density in slaughter cages than this, without the Food Safety Authority's approval.*". In 2018 §46 was revoked, and §25 extended with the exemption for slaughtering cages from density restrictions at the same time [80].

Stocking salmon at high densities, for prolonged periods, poses a significant welfare issue [98]. Within a production cage at sea, oxygen consumption increases at high stocking densities, potentially causing hypoxia in the salmon. Lower salmon welfare scores, based on the condition of body and fins and plasma concentrations of glucose and cortisol, are associated with stocking densities above 22 kg/m^3 [99]. Norwegian regulation require stocking densities lower than 25 kg/m^3 in production cages [80]. Low stocking densities are not a perfect measure of fish welfare, as rates of aggression in Atlantic salmon peak at 15 kg/m^3 in seawater tanks [100].

For live transportation of farmed fish, Norwegian regulation does not specify the maximum values of stocking densities. Instead, regulation states: "*Transport time and density must be adapted to conditions that may have an impact on fish welfare. For longer transports, special attention should be paid to water quality, water temperature, and stocking density.*" [45]. Ensuring good water quality includes monitoring of CO_2 and O_2 levels, pH values, salinity and flow velocity (particularly in a closed-well system) [58]. The Royal Society for the Prevention of Cruelty to Animals (RSPCA) welfare standards provides a recommendation of transport stocking densities, seen in Table 3.1 [101]. The standard is based on industry, science, and veterinary expertise [102]. There are also indications that Norwegian LFC companies use this standard to some extent [103]. Table 3.1 indicates RSPCA recommended maximum cargo capacity of a 3000 m^3 LFC, when transporting various category of salmon.

Table 3.1: RSPCA recommended maximum stocking densities for Atlantic salmon [101]

Live weight of fish [kg]	Maximum stocking density [kg/m^3)]	Maximum cargo capacity using a 3000 m^3 LFC [tonnes]
5	125	375
4	110	330
3.5	100	300
3	90	270
2	75	225
1	60	180
0.1	45	135

Salmon with a live weight of 0.1-1 kg are typically smolt. In the context of the modern Norwegian aquaculture's scale, LFCs carry out most smolt transports. Smolts usually weigh 100-250 grams, when transported to sea production cages [69]. In recent years the rearing of so-called "post-smolt" has become more common [104]. Post-smolt are salmon that has gone through the smoltification process. The term post-smolt describes larger smolt up to 1000 grams, not yet released into on-growing production cages. Whether a company chooses to use smaller or larger smolt depends on several factors that are not within the scope of this thesis. However, the use of larger smolt has become widespread in Norway. Table 5.1 indicates the LFC cargo volume needed for transporting (a) 200 000, (b) 400 000 and (c) 600 000 individual smolt (the maximum allowable number of individual salmon in one production cage is 200 000 [80]). Loading a six cage production site (1.2 million individuals) with smolt weighing 100 grams can be done in one single round trip using a 3000 m^3 LFC. Although the MSD increases when transporting larger salmon, a 3000 m^3 LFC would have to perform 7 round trips to transport the same number of smolt weighing 1000 grams.

Table 3.2: Cargo volume needed for transporting smolt of different average sizes. Maximum stocking density (MSD) is determined by the weight of the smolt.

(a) 200 000 smolt transported

Weight of smolt [kg]	0.1	0.25	0.5	1
MSD [kg/m³]	45	50	55	60
Total biomass [tonnes]	20	50	100	200
cargo volume needed [m³]	444	1000	1818	3333

(b) 400 000 smolt transported

Weight of smolt [kg]	0.1	0.25	0.5	1
MSD [kg/m³]	45	50	55	60
Total biomass [tonnes]	40	100	200	400
cargo volume needed [m³]	889	2000	3636	6667

(c) 600 000 smolt transported

Weight of smolt [kg]	0.1	0.25	0.5	1
MSD [kg/m³]	45	50	55	60
Total biomass [tonnes]	60	150	300	600
cargo volume needed [m³]	1333	3000	5455	10000

According to statistics from the Norwegian Directorate of Fisheries, 304.4 million smolts were transferred from shore to production sites in 2018 [9]. The number of transferred smolt were similar in the period 2014-2017. Assuming an average weight of 250 grams, this would imply a total biomass of 30400 tonnes. With an MSD of 45 kg/m^3, a total RSW tank volume of around 1.7 million m^3 would be needed to carry out all the transfers for the entire year. In 2017 there were 67 LFCs in operation in Norway, with an average gross tonnage (GT) of approximately 2800 [105]. Figure 3.16 indicates the relationship between LFC RSW tank volume and GT. The Figure is based on the same research as Figure 3.4. The relationship between RSW tank volume and GT is approximately 1:1 for LFCs. Therefore, the average cargo capacity of an LFC in 2017 was around 2800 m^3. All smolts in 2018 could at optimum be transported to production cages in 604 transport missions. Evenly distributed between the 67 LFCs in 2017, this would imply an average of little over nine transport mission per vessel per year.

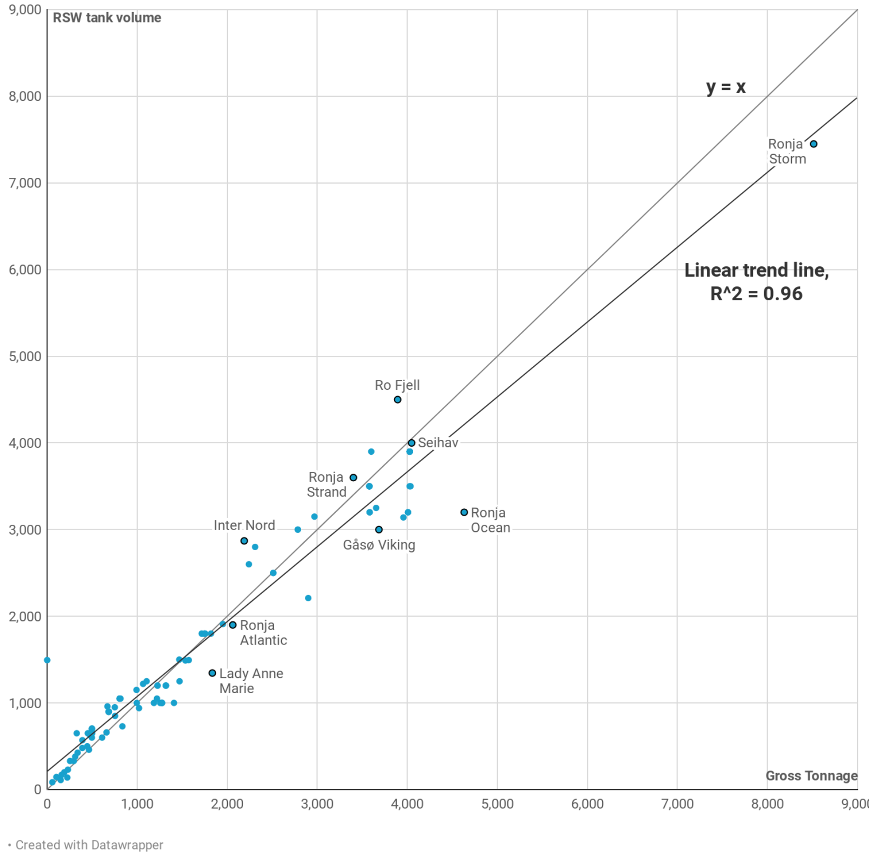


Figure 3.16: Norwegian LFC cargo capacity in RSW tank volume [m^3] versus gross tonnage (GT).

3.4.2 LFC economy and global shipping markets

Most LFC owners in Norway operate mainly within three of the four shipping markets, as defined by Stopford: The *shipbuilding market*, the *sale, and purchase market*, and the *freight market* [106]. By a large margin, most modern LFCs have been purchased and owned by Norwegian companies, backed by the funding of Norwegian banks. The world's largest LFC, "Ronja Storm", had an initial contract valued at 500 million NOK [107], while LFCs over 3000 m^2 range typically have contracts worth 300 million NOK or more. Designs from Norwegian companies dominate the modern LFC market, overseas shipyards construct them before final outfitting in Norway. Second-hand ships are sold and bought within all markets that farm salmon at sea (Chile, UK, Faraoe Islands, Iceland, Canada, Tasmania, and others). A trend seems to have been that second-hand vessels from Norway continue to transport salmon for extended periods overseas. Although some LFCs today are built mainly for other salmon farming industries other than the Norwegian one (e.g., "Ronja Storm" operating in Tasmania), the new LFCs remain in Norwegian ownership (Sølvrans AS owns and operates "Ronja Storm"). Since most specialized LFCs have been built within the last 30 years, few have reached the *demolition market*.

LFCs typically operate in the salmon freight market. Contracts that are made between farmers and shipowners are mainly *time charter* contracts [68]. The time charter gives the charterer (i.e., the salmon farmer) operational control of the ships, while ownership and management are in the hands of the shipowner [106]. The shipowner is responsible for OPEX, while the farmer pays the VOYEX. Furthermore, these are long-term or *period* charter contracts, lasting anywhere between a year to several years. In Norway, a long-term charter contract is often a prerequisite to obtaining funding for new LFC building projects. The farmers can allow shipowners, operating under charter contracts, to lend their services to other farmers [108]. The price of hiring an LFC depends on the type of contract the LFC operates under (charter or spot) and the negotiation between farmers. An LFC with a cargo capacity of 1800 m^3 has an estimated price of around 7 500 NOK/hour (2015 figures). Some farmers state hiring prices of around 15 000 NOK/hour during delousing operations (2017 figures, unspecified vessel size) [109].

The details of individual charter contracts differ, but for the farmers, the services promised by the LFC owners must be available when needed [68]. Availability alone partially explains why farmers have favored long-term time charters with LFC owners. History can also explain this subcontracting of transportation and other services. In recent history, salmon farming companies have become huge, multi-billion dollar businesses (Mowi ASA had a market cap of $ 11.4 billion as of May 2019 [110]). A report from 2019 found that a considerable amount of new LFCs built in recent years are owned by salmon farming companies, instead of independent ship owners [68]. This trend in integrating salmon transport services seems to be a combination of the following needs; 1) more value chain control; 2) more flexibility and responsiveness; 3) able to follow the development of technology; 4) lowering transport supplier prices. As previously mentioned, LFCs take on other missions than transporting smolt and harvest salmon. The industry refers to LFCs as ”multi-purpose” vessels, as they have to meet many of the farmers' requirements.

In addition to transporting smolt and harvest salmon, LFCs are used for sorting operations and salmon disease treatment, particularly delousing operations. Delousing puts a significant strain on salmon, especially those with an already weakened health [10]. In many cases, increased salmon mortality rates occur in production sites after treatment. The biology of the salmon is essential to understand the effects of disease and parasites and to limit treatment-related mortality. It is also essential to understand why welfare is important to ensure a high quality of processed salmon.

4 Atlantic salmon biology and challenges related to farming it

Atlantic salmon (*Salmon salar*) has been farmed on an industrial scale in Norway for more than four decades. The first effective breeding programs for Atlantic salmon started with genetic research in the early 1970s, using 40 wild Norwegian river strains [111]. Since Atlantic salmon has a generation interval of four years, breeders hatched four populations of salmon cohorts (or substrains) between 1972 and 1975. During the years, the breeding programs' salmon families have been selected for growth rate and body size (from 1972), late maturation (from 1980), disease resistance (furunculosis susceptibility from 1989 and ISA from 1992) and quality (fat content and fillet color from 1990) [112]. This chapter focuses on the challenges related to salmon biology, specifically on the challenges that have implications for the vessels used for salmon transportation.

4.1 Farmed salmon life cycle

The life cycle of farmed Atlantic salmon follows the same discrete stages as the wild salmon. However, their phenotypes (physical properties affected by an organism's set of genes and environmental influences on this genotype) are quite different[111]. The entire life cycle of the salmon is under full or partial control of humans. Feed regimes and environmental factors like water temperature and quality can be optimized. A wild salmon may spend several years of its life in freshwater before migrating out to sea. A farmed salmon, under the right circumstances, is hatched and harvested within two years [69]. Figure 4.1 illustrates the main stages of the salmon's life cycle [113].

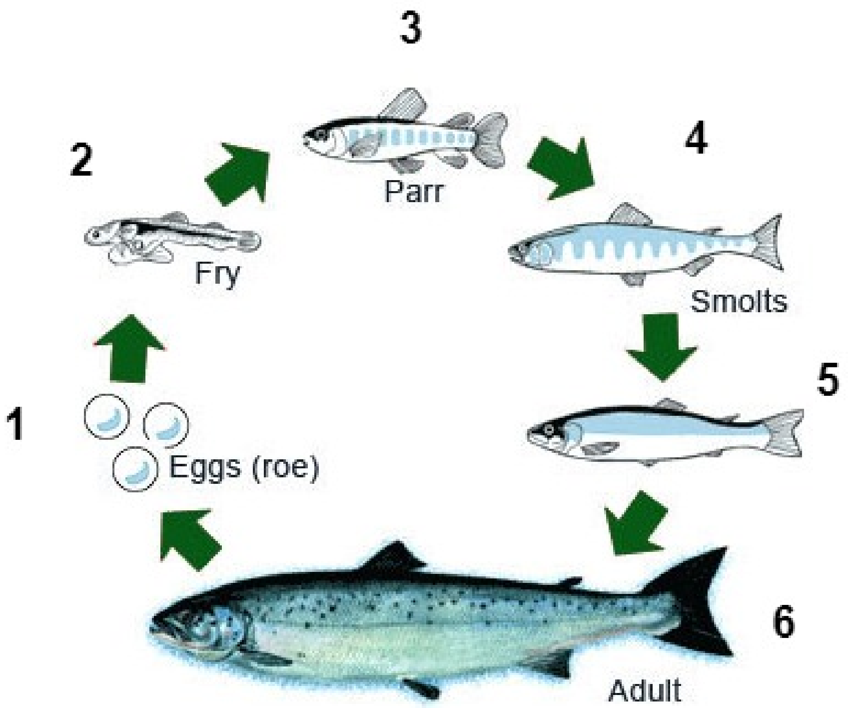


Figure 4.1: The main stages in an Atlantic salmon's life cycle [113].

Atlantic salmon are *anadromous*, spending their first life stages in freshwater [114]. During these early stages (1-4 in Figure 4.1), the wild salmon is particularly vulnerable to environmental impacts. In contrast, farmed salmon spawn in hatcheries on land. In the hatcheries, the abiotic (e.g., light, temperature, and nutrient composition) and biotic (e.g., food availability, parasites, disease, and predators) factors are more or less controlled. Approximately 85 % of all Atlantic salmon eggs survived until the smolt stage in the 2016-17 season [70]. A large part of this attributed to genetic research, in the case of the 2016-17 season, mainly due to improved resistance towards Infectious pancreatic necrosis (IPN).

After approximately a year in an on-shore hatchery, the salmon is ready for transfer to sea. Before transfer, the salmon has to adjust to the increased salinity of seawater [114]. This process is known as *smoltification*. In Norwegian aquaculture, smolt sizes of 100-250 grams are standard at the time of smolt release [69]. However, the production of post-smolt has become more common due to an expectation of more efficient use of the maximum permitted biomass (MPB), reduced exposure time to salmon lice, higher growth, and improved fish welfare [104]. If the salmon has not entirely gone through the smoltification process, there is a risk of high mortality after release in seawater and reduced growth for 1-2 months [102]. Physiological disturbances are also more significant if seawater temperatures are high (> 14°C), than for medium (10°C) and low (< 7°C) temperatures. For the generations of smolt released between 2002 and 2016, the percentage of salmon lost at sea before harvesting was between 18 % and 22 % [70]. Close to all production cages in Norway are open, in the sense that seawater can flow through them. Open cages have the advantage of free water renewal and dispersion of waste particles. A drawback to open cages is exposure to the surrounding environment, i.e., the seawater.

4.2 Rigor mortis and stress response in salmon

Section 3.3.2 briefly discussed the importance of pre-rigor processing in slaughterhouses. Rigor mortis occurs in all animals after death [102]. When a salmon dies, its metabolic processes are still active, and its muscles are soft and elastic. Shortly after death, catabolic (the deteriorating part of metabolism) processes consume the remaining oxygen in the muscle. After that, anaerobic metabolism consumes energy in the form of ATP (the energy source for muscle contraction). The anaerobic metabolism continues, and glycogen becomes lactic acid to produce more ATP, which in turn lowers the muscles' pH value. Low pH values affect the conversion of glycogen to lactic acid, and ATP and the metabolism stops. The muscle is locked in a contracted state, as no more ATP can be bound to the muscle cell protein myosin; therefore, myosin can not be released from actin (another muscle cell protein). The most important factors affecting the onset of rigor mortis and its intensity are the glycogen reserves, the pH value, and temperature of the muscle.

Every animal has a fundamental need to be able to escape danger [102]. Fish is not an exception to this, and perceive many operations in aquaculture as threats, responding with fear and panic. Examples of such operations are handling and crowding. Stressed salmon respond with either fight or flight, involving rapid muscle contractions. This quickly causes anaerobic energy transformation, increasing the level of lactic acid in the muscle. Without the possibility to restore normal aerobic metabolism and pH values, e.g., if the salmon dies, rigor will occur sooner than if the salmon was unstressed. Understanding fish welfare is essential for anyone who handles salmon. Operators of systems that handle the fish right before the time of death have to have an understanding of fish welfare. Norwegian regulation points out the importance of fish welfare numerous times.

4.2.1 Fish welfare

The Norwegian Animal Welfare Act states that: *"Animals have an intrinsic value which is irrespective of the usable value they may have for man. Animals shall be treated well and be protected from danger of unnecessary stress and strains."* [115]. The act, implemented in 2010, includes fish within its scope. The law does not differentiate between species, but the parts concerning the transport and slaughter of farmed salmon can be summed up as follows:

- Salmon must be *"...taken care of by sufficient and technically competent personnel"*
- *"Anyone marketing or selling new forms of operation, methods, equipment, and technical solutions for use on animals or in animal husbandry shall ensure that these have been tested and found suitable for the sake of animal welfare."*
- *"Transport should be carried out in a manner that minimizes the burden on the* (live) *animal. Animals should only be transported when they are in such a state that it is safe to carry out the entire transport."*
- *"The means of transport must be suitable for the safety and uniqueness of the animals. Animals must have the necessary supervision and care during transport."*
- *"Animals that are owned or otherwise kept in human custody must be anesthetized* (stunned) *before killed. The stunning method should cause loss of consciousness, and the animal should be unconscious from before the onset of the killing and until death occurs. Requirements for anesthesia before killing do not apply if the animal is killed using a method that causes immediate loss of consciousness. After the killing is performed, it must be ensured that the animal is dead."*
- During inspections the person responsible shall *"...make available the necessary premises, fixtures, work aids and tools free of charge for the exercise of the supervision and otherwise assist in arranging the supervision."*
- *"The animal keeper must ensure that animals receive proper supervision and care, including ensuring that:""...animals are protected against damage, disease, parasites, and other hazards. Sick and injured animals should be adequately treated and killed if necessary, to limit the spread of infection."*

What constitutes good welfare for fish, specifically farmed Atlantic salmon? A common consensus of "good" animal welfare does not exist within the scientific community and society in general [102]. Different viewpoints, depending on role in society are summed up in Table 4.1.

Table 4.1: Different views of animal welfare [102]

Role in society	View of what constitutes good animal welfare	Key aspect(s)
Naturalists and veterinarians	A healthy animal with good growth and performance.	Animal welfare = biological function
Animal welfare organizations	Animals are kept in a natural environment, are allowed to grow and can perform in a natural way, are given the possibility to perform innate, species-specific and instinctive behavioral patterns.	Animal welfare = right of natural life
Animal welfare activists, animal welfare researchers, and pet owners	Animals without prelonged negative emotions (e.g. pain and fear) and that are given the opportunity to have positive experiences can be said to have good welfare.	Animals have feelings and affective states

Arguably the Norwegian aquaculture industry is still characterized by trial and error. Numerous ideas for solving problems like the salmon louse have come about in a short time. Research and optimization of methods have not been able to keep up [10]. In many cases, the treatment has reduced the welfare of salmon and increased mortality. For the salmon to grow and to maintain fish welfare, the industry has to deal with diseases and parasites. However, one option is to kill the fish. Depending on several different factors (such as size, condition of the fish, expected sales price, type of treatment available), this could be the best option, as feeding the fish and treating the disease or parasite can be a costly affair.

4.3 Disease and parasites in Norway

Many of the disease outbreaks at production sites take place during the first months of smolt release [116]. The primary stressor for the salmon during transfer is not the transport itself, but rather the handling before the transport and loading and unloading operations. However, smolts transported during rough weather conditions have higher mortality rates in the following months after release. As previously mentioned, salmon released before going through smoltification has reduced growth in the first couple of months after release. Nutritional stress and starvation negatively affect the mucus production in salmon [102]. The mucus acts as a biochemical interface between the salmon and the seawater. Mucus is involved in a series of biological functions, one being disease resistance. The salmon's skin is its main barrier against infections [102]. Despite being covered with scales, the skin is soft and susceptible to mechanical injury. A bite from a competing fish or predator can be lethal. Many infectious and parasitic diseases affect farmed salmon.

Previously, the most dominating diseases in Norwegian salmon farming have been the infectious diseases Pancreas disease (PD) and Infectious salmon anemia (ISA) [65]. In 2019, 90 % of farmers reported the viral disease Cardiomyopathy syndrome (CMS) as the number one cause of salmon mortality [117]. The parasitic Salmon louse is arguably the biggest challenge in salmon farming today. Farmers reported injury, as a result of mechanical delousing, as the number one welfare concern in 2019, and after CMS, the most significant contributor to salmon mortality.

4.3.1 Pancreas disease (PD)

Pancreas Disease (PD) is a contagious viral disease caused by the virus *Salmonid alphavirus* (SAV) [117]. Infected salmon has extensive damage in the pancreas and inflammation of the heart and skeletal muscle. PD causes increased mortality in Atlantic salmon production, but the data on observed mortality varies [118]. However, cases of high mortality exist, particularly for salmon infected with the SAV3 variant [117]. Figure 4.2 shows the location of production sites with confirmed PD cases in 2019. As of 2020, PD does not exist in northern Norway. SAV3 is endemic in the western part of Norway, while SAV2 is widely spread north of Møre & Romsdal. PD typically causes loss of appetite in salmon, limiting growth and increasing the feed conversion ratio (FCR) [119]. The loss of appetite increases the number of emaciated salmon, which is discarded during processing [117]. PD can be long-lasting (1-32 weeks) and cause premature harvest [102].

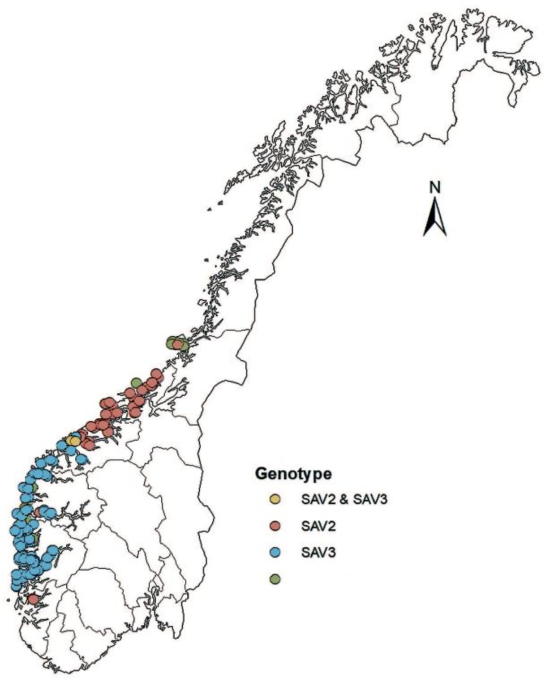


Figure 4.2: Production sites with Pancreas disease (PD) and their genotypes in Norway in 2019. Green dots are Salmonid alphavirus' (SAVs) of unknown genotype [117].

No effective treatment for the disease exist, although vaccines seem to limit the spread and the severity of the disease [117]. Norway has established surveying zones and combating zones (PD-zones) to limit the effect of the disease and its spread. Transportation of fish in or out of a production site without the NFSA's approval is illegal [11]. It is illegal to unload salmon with, or suspected to have, PD into slaughterhouse waiting-cages. The NFSA can make exceptions to this requirement if the risk of contagion is or the transport is necessary to control the outbreak. The regulation further states that in cases of unavailable closed transport and slaughtering (direct-unloading), extraordinary exemptions can be made. These exemptions can only be made until January 1st, 2021. From this date when transporting aquaculture animals from lower health category segment concerning list 2 diseases (includes

PD), transport water should not be replaced when the transport passes through a higher health segment [45]

4.3.2 Cardiomyopathy syndrome (CMS)

Cardiomyopathy syndrome (CMS) is a serious contagious viral heart disease that affects farmed salmon in the sea phase. [117]. As of 2020, CMS is one of the largest factors contributing to economic loss in Norwegian aquaculture. Sudden instances of mortality, without prior clinical signals, are common [102]. Instances of sudden salmon death occur during stress-related operations, such as handling, transport, and delousing. The disease tends to cause mortality near the end of a production cycle when most of the production costs are already spent [117]. Figure 4.3 shows production sites with CMS in Norway in 2019. Around 100 cases of CMS per year is considered normal. The counties Nordland and Troms & Finnmark experienced a slight reduction of cases between 2017 and 2019, while Hordaland has seen an increase of cases the past three years (19 in 2018 and 27 in 2019).

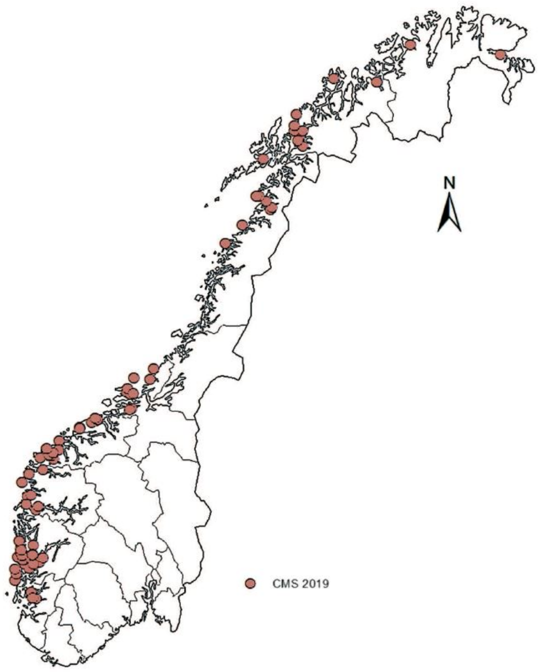


Figure 4.3: Production sites with Cardiomyopathy syndrome (CMS) in Norway in 2019 [117].

CMS weakens the salmon's heart wall, subsequently reducing the salmon's resistance to stress [117]. The shift towards the use of mechanical delousing methods poses a risk of sudden mortality during production. Cases of CMS in the early stages of the sea phase increases the risk as salmon often go through several delousing operations during one production cycle.

4.3.3 Salmon louse (*Lepeoptheirus salmonis*)

The greatest challenge the Norwegian aquaculture industry has been facing for several years is the Salmon louse (*Lepeoptheirus salmonis*) [117]. The louse is a parasitic copepod, living of the skin, mucus and blood of most salmonids. Thes louse has eight life stages, the last five of which are parasitic to salmon. In the first three planktonic stages, ocean currents can spread the louse over vast distances (if the sea temperature is low the planktonic stage can last several weeks). Numerous amount of lice in the first three parasitic stages can cause wounds and anemia in fish. These wound make the salmon more susceptible to other infections and issues with osmotic regulation. Severe numbers of lice and subsequent strain on the fish can cause death.

Due to the louse's capability of being transported over longer distances by currents, coupled with the fact that it can infect wild salmon, makes the salmon louse one of the biggest environmental challenges in salmon farming [117]. The number of adult female salmon louse in Norwegian production sites follows a cyclic pattern, with the largest numbers seen during fall. The regulation concerning salmon lice sets a strict limit to the amount of adult female lice per fish a production site can have. From Nord-Trøndelag to the south of Norway no more than an average of 0.2 adult female lice per salmon is allowed between the beginning of week 16 and the end of week 21, at any given time (in the northern part of the country this limit is valid between the start of week 21 and the end of week 26) [120]. The rest of the year, no more than 0.5 adult female lice per salmon are allowed at any given time. The number of lice has to be reported every week. The reason for the lower limit during spring is that this is the period when wild salmon smolts emigrate from freshwater to the sea [121].

The NFSA can order the initiation of the slaughter at a site, and possible prolonged fallowing of the site if the limits are not met [121]. Early slaughter and unnecessary fallowing imply substantial economic losses for farmers and is a big incentive for combatting the louse. Techniques for combating the salmon lice can be divided into: 1) Non-pharmaceutical methods with handling; 2) Non-pharmaceutical method without handling; 3) Preventive technological measures; 4) Preventive biological measures and 5) Combination models, that jointly uses one or more of the methods [109]. Salmon in Norway have developed resistance toward many of the pharmaceuticals (e.g., hydrogen peroxide) used over the years [117].

Farmers are, to a greater extent using non-pharmaceutical methods with handling. These include thermal delousing, mechanical delousing, and freshwater delousing. Thermal delousing essentially bathes the salmon in water with higher temperatures, which causes the lice to detach from the salmon. Mechanical delousing utilize either high-velocity water spray or brushes to remove lice. A study from 2019 found that from 2012 to 2017, the number of delousing operations in total increased with 40 % [10]. Furthermore, the study found that thermal delousing caused the most significant increase in salmon mortality after treatment (elevated mortality rates in 31 % of treatments). Mechanical delousing caused elevated mortality rates in salmon after 25 % of all operations. Both thermal and mechanical delousing operations had higher mortality rates at low (4-7°C) and high (13-16°C) temperatures. Large salmon (>2 kg) was found to be more susceptible to increased mortality than smaller fish. Freshwater treatment (e.g., bathing salmon in freshwater in LFC RSW tanks) has shown promising results [122]. However, the process is time demanding; therefore, expensive for farmers. Also, salmon lice can develop resistance towards freshwater treatment [117]. Thermal, mechanical, and freshwater delousing operations all involve handling the salmon. The crowding and pumping operations are, as discussed previously in this chapter, stress-inducing operations for the salmon. Careful handling of sick fish is essential, as there may be an increased risk of mortality when treating sick fish [123].

As mentioned above, regulation dictates the limit of adult female lice per salmon at a production site [120]. The challenge related to salmon lice is still a considerable challenge in Norwegian aquaculture and one of the main reasons for the limit in the growth of production volume [44]. The NFSA has proposed updated to the regulation concerning salmon lice [124]. The new regulation limits the number of adult female louse during smolt emigration on a production zone level, as smolt emigration differs in time from north to south. Furthermore, the new regulation will define the limit of adult female lice on a production*cage* level, not only production site. The regulation will also affect the transport of salmon to slaughterhouses with waiting-cages. If the slaughterhouse is in a production zone with a limit of 0.2 adult female lice, the salmon has to come from a production cage with an average of 0.2 adult female lice or less, if the transport is open (e.g., using open-wells in LFCs).

The regulation implies that delousing operations could intensify, as an entire site can report average lice numbers below the limit, while individual cages can have average numbers above the limit. The increased rate of delousing operations could increase the risk of post-treatment mortality. Also, the regulation would decrease the logistical advantage of waiting-cages. A production site with six production cages can, e.g., have four cages with averages of 0.4 lice per fish and two with 0.6. The site has an average of 0.47 lice per fish. The indented slaughterhouse uses waiting-cages with a limit of 0.5 adult female lice per fish. In this example, the two production cages will have to reduce the number of lice or transport the salmon to a slaughterhouse that uses direct-unloading. The following chapter focuses on the use of SBVs and the mapping of industry requirements for this vessel type.

5 Mapping of industry requirements

The motivation for this chapter is to identify requirements in the Norwegian aquaculture industry that affect the designs of salmonid transportation systems. Terminology coined by Pahl et al. is used, categorizing requirements as either *wishes* or *demands* [17]. These wishes and demands form the basis for a requirements list. The intent is to check vessel functions and onboard systems against the list. By having a complete understanding of perceived industry needs (wishes) and regulation (demands), a requirements list can be created more conscientiously. The remaining chapter of this thesis focuses on extending and refining these requirements in the context of the SBV concept.

Chapter 3 partially discussed the situation of the Norwegian salmon market and how it developed. How the market is developing, and the drivers within it indicate requirements from the final stage of the salmon production cycle 8(i.e., harvest). These requirements affect the way the salmon is processed, and in turn, systems that are a part of that process. Furthermore, regulations can often be translated into requirements in the form of demands (e.g."*farmed fish must be sorted domestically...*" [93]). In some instances, regulations are open for some interpretation (e.g., "the vessel must be properly cleaned and disinfected"). In these instances, regulation can provide requirements in the form of *wishes*, classified as being of major, minimum, or minor importance. Chapter 4 presented some significant challenges regarding salmon biology. It is essential to be aware of these aspects when designing systems that interact with them.

The operational context of the transport system can primarily elucidate basic (e.g., the safety of crew) and performance type requirements (e.g., vessel speed). Some operations are common denominators for all vessels transporting salmon, e.g., interaction with net cages. In contrast, others are area and concept specific (specific weather patterns, currents, temperature, weak salmon, or salmon close to death).

In a real-life project the customer, i.e. the shipowner, will change his demands and wishes [17]. Partially because his knowledge increases during the course of the project, but also because of changes in the market the vessel is intended to operate in. The direct interaction with a specific customer, an important part of requirement *elucidation* has not been done in this thesis. Secondhand information regarding current SBV projects and development has been communicated through my supervisor at Moen Marin.

5.1 Situation analysis

The area of interest is limited to that of the salmonid transportation market in Norway. Figure 5.1 depicts a conceptual overview of requirements in the aquaculture transport segment (blue and green rectangles), as a sub-set of all requirements within the Norwegian aquaculture industry. Within the transport segment, there are several transportation requirements for different transport categories; transport of people, feed transport, transportation of equipment and supplies, and products.

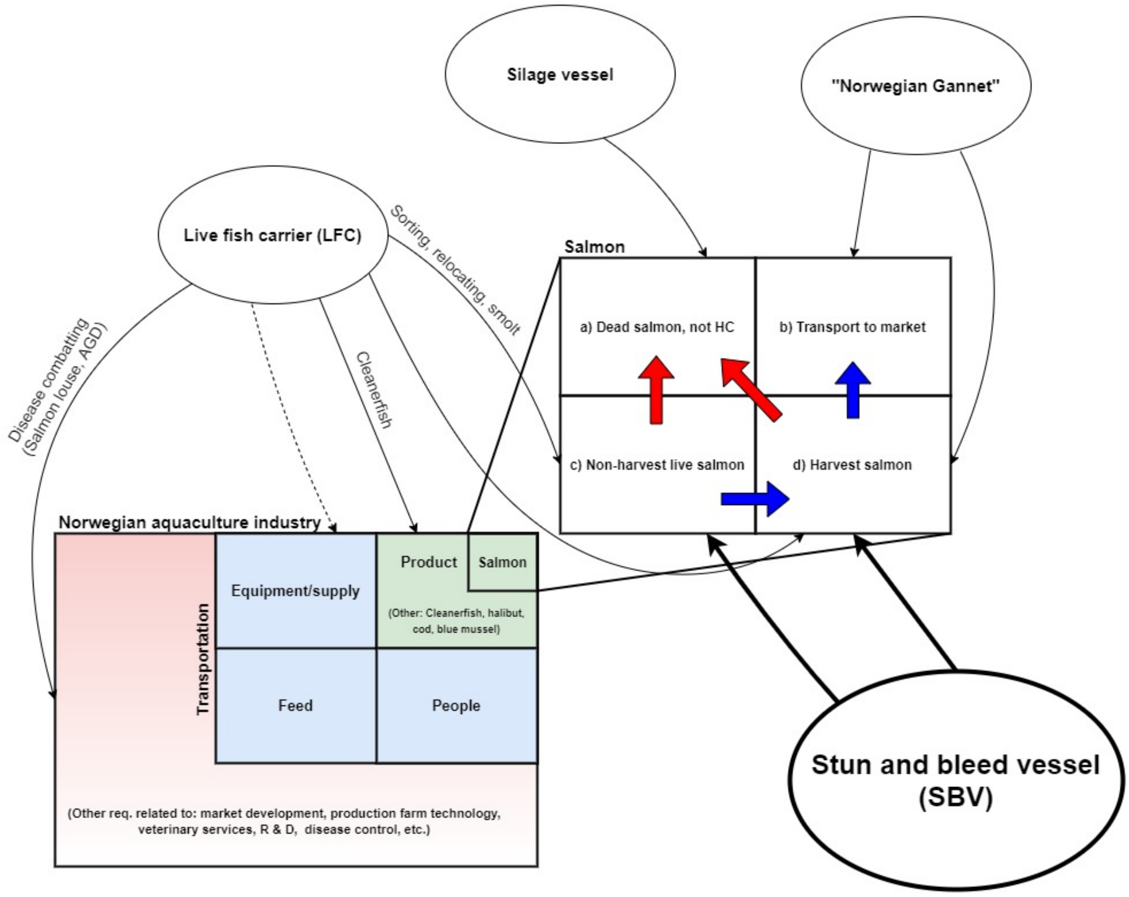


Figure 5.1: Overview of the situation related to transport requirements in the Norwegian salmonid transport segment (top right matrix). a) Dead salmon, not meant for human consumption, b) Transportation to market, c) Non-harvest live salmon, d) Harvest salmon. Blue arrows indicate a value increase of the product, red a decline in value.

Products that generate cash flow for the farmers (i.e., farmed animals) are defined as "product" in the figure (green rectangle). Transport requirements related to salmon are defined as the following: a) dead salmon, not meant for human consumption; b) transportation of salmon to market; c) non-harvest live salmon (e.g., salmon moved from one site to another); d) harvest salmon. Within the salmon-transport-requirement "matrix" the blue arrows indicate a positive, value increasing transition (i.e., salmon growing to harvest size and processed salmon making it to market), red arrows indicate a loss for the farmers (e.g., salmon dying during delousing operation or during transport to a slaughterhouse). Examples of ship types that meet both transportation and other requirements outline the figure.

Chapter 3 presented the multiple roles of the LFCs in the industry. Figure 5.1

reflects this, as LFCs meet multiple requirements (indicated with arrows). Within the salmonid transportation segment, LFCs are the most effective systems for transporting large amounts of live fish. A significant amount of salmon dies in the sea phase (more than 53 million individual salmon in 2019). By law, farmers have to remove dead fish matter from their cages daily, stored as silage in containers at the site [80]. The dead fish are stored as silage in containers on-site and picked up by specialized chemical tanker vessels (silage vessels). In 2011 this service cost farmers approximately 2 500 NOK/tonne of silage [125]. As discussed in Section 3.3.3 the only system today that can both harvest and deliver salmon directly to the overseas market is "Norwegian Gannet". However, this system type's future is highly uncertain due to recent changes in regulation.

The last system depicted in Figure 5.1 is the stun and bleed vessel (SBV). SBVs are expected to meet requirements related to c) (non-harvest live salmon) and d) (harvest salmon). When transporting salmon of type d) the SBV is competing directly with the LFC. In some cases, the harvest-ready salmon is weak due to disease, and therefore live transportation is not advised [60]. In these instances, fish may end up dead in the production cages or during live transport before reaching the processing lines. In Figure 5.1 this is depicted in the top right matrix with a red arrow from d) to a). The SBV can potentially be used to avoid loss of value by preventing salmon, in the middle of the production cycle, from becoming dead salmon not meant for human consumption. Figure 5.1 illustrates this with a red arrow from c) to a). An example of use is to remove weak fish before a delousing operation (can potentially be used for direct human consumption) or fainted salmon after a delousing operation (can be used indirectly for human consumption, e.g., nutritional supplements).

5.1.1 Shipowners in the market

In Norway, there are relatively few large companies that operate within the salmonid transport marked. The largest companies in Norway as of February 2020 (either by sales figures or fleet size) are seen in Table 5.1. Three categories are used to describe the companies operating ships: 1) Shipowner (one company is the majority shareholder); 2) subsidiary companies (owned by a parent company); 3) joint ventures (shared ownership of vessels between two or more companies). The column "Vessel type" contains the established abbreviations LFC and SBV and service vessel (SV) and feed carrier (FC).

Table 5.1: List of salmonid transport vessel owners as of February 2020 and key company figures. Sales and EBIT values are in NOK million and are from financial reports for 2018.

	Sales	EBIT	EBIT margin	Company type	Vessel type	No. vessels
Rostein	902.5	287.3	31.8 %	Shipowner	LFC	14
Sølvtrans Rederi	813.8	451.1	55.4 %	Shipowner	LFC	22
Norsk Fisketransport	561.8	215.8	38.4 %	Subsidiary	LFC	8
Frøy Rederi	278.9	83.2	29.8 %	Subsidiary	LFC, SV	8, 12
Oppdretternes Miljøservice	247.0	2.1	0.9 %	Joint venture	LFC, SV	0?
Nordlaks Transport	216.7	167.1	77.1 %	Subsidiary	LFC	0
Intership	187.1	5.2	2.8 %	Shipowner	LFC	7
SeiStar Holding	169.9	43.5	25.6 %	Shipower	LFC, SBV, SV	3, 2, 6
Brønnbåt Nord	83.0	34.9	42.1 %	Joint venture/ subsidiary	LFC	2
Godfisken AS	36.2	18.4	50.8 %	Joint venture	SV/SBV	1
Salmon Star	30.5	5.9	19.3 %	-	-	-
Napier	29.6	9.2	31.1 %	Shipowner	SBV	3
Volt Service	27.8	11.4	41.0 %	Subsidiary	SBV, SV	3
Gerda Sæle	22.3	4.7	21.1 %	-	-	-
Amar Shipping	7.5	-8.9	Negative	Subsidiary	SBV, SV	0, 2
Aquaship	6.9	2.8	40.6 %	Shipowner	LFC, SBV, SV, FC	10, 4, 8, 5
Hav Line Gruppen	0.5	-11.9	Negative	Shipowner	Slaughter vessel	1
DESS Aquaculture Shipping	0.0	-7.4	Negative	Subsidiary	LFC, SBV, SV	8, 1, 3

The seven largest companies, in terms of sales, are companies mainly operating LFCs. Seven Norwegian companies own SBVs. Their average EBIT values are 9.9 million NOK.

5.1.2 Salmon price, its volatility and characteristics

Salmon export prices from Norway vary according to demand and the weight class of the salmon [126]. An example of how price varies across salmon weight classes can be seen in Figure 5.2, while the distribution of exported salmon weight can be seen in Table 5.2. Most exported salmon comes from the weight classes 3-4 kg, 4-5, and 5-6, making up approximately 20, 30, and 20 %, respectively, of the yearly distribution. For more information about the NASDAQ Salmon Index, see Appendix B.

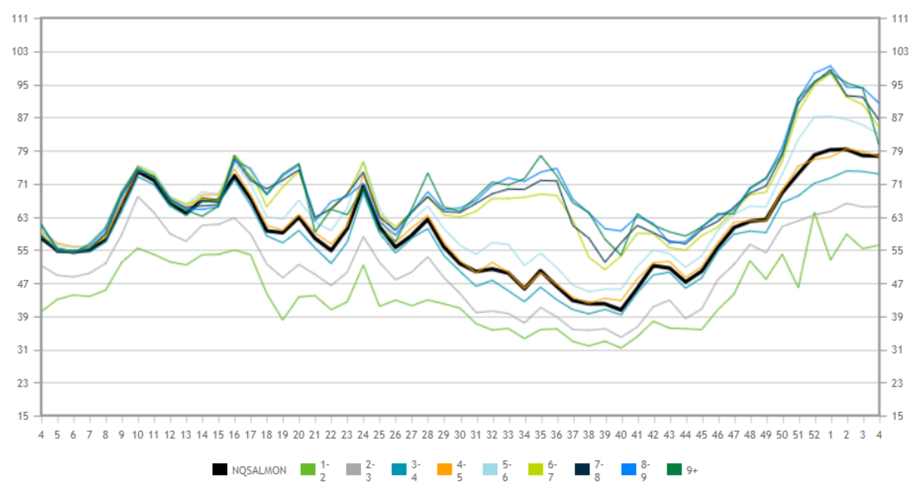


Figure 5.2: NASDAQ Salmon Index: Historical prices of salmon weight classes from February 2019 to February 2020 [126].

Table 5.2: Average yearly percentage distribution of salmon weight classes, 2013-2019 [126]

	1-2 kg	2-3 kg	3-4 kg	4-5 kg	5-6 kg	6-7 kg	7-8 kg	8-9 kg	9+ kg
2013 (week 14-52)	0.63	8.42	24.95	30.44	21.23	9.41	3.46	1.09	0.37
2014	0.77	7.87	22.24	29.00	22.86	11.07	4.43	1.38	0.37
2015	1.08	8.55	24.04	29.94	20.77	9.54	4.12	1.45	0.51
2016	1.47	10.92	24.12	29.96	20.71	7.61	3.51	1.27	0.43
2017	2.00	9.53	21.01	30.22	23.49	8.67	3.58	1.17	0.33
2018	1.41	9.80	22.80	31.03	21.46	8.43	3.33	1.32	0.40
2019	1.02	10.39	27.47	31.17	19.52	6.25	2.87	1.04	0.29
Average 2013-2019	1.20	9.35	23.80	30.25	21.44	8.71	3.61	1.25	0.39

While salmon production varies with the yearly seasons, as growth rates are affected by conditions like sunlight and sea temperatures, the salmon price shows little seasonal variation [127]. However, in years with lower than expected biomass growth in the months leading up to summer can cause ”spikes” in salmon prices [128]. Low biomass growth can indicate lower than expected growth of salmon due to poor growth conditions (e.g., lower sea temperature, or disease), or a loss of biomass due to increased mortality. As the spring/summer period is a period with high growth rates, the alternative cost of slaughtering is high, so prices must increase to compensate farmers. The volatility of the salmon price has increased in recent years [129]. This is largely due to the volatility of other consumables, and the volatility is lower than that of wild-caught fish. In fact, salmon is considered one of the fish species with the lowest price volatility in the market [130]. Economic inefficiency in Norwegian salmon farming industry is mainly caused by temporary shocks, such as disease outbreak leading to early harvest or destruction of fish [131].

5.1.3 Identifying important stakeholders in the market

There are many conflicting and competing interests in this market segment. To a certain extent, an SBV has to compete with all systems presented in Figure 5.1. Systems that are competing directly with the SBV are the LFCs and ”Norwegian Gannet”, while silage vessels are indirect competitors as they use silage as a raw material in a completely different value chain. In order to estimate the importance of both competitors and other stakeholders within the transportation market, a *Stakeholders analysis* has been performed. The results of the analysis are plotted in a Power/Interest Matrix, seen in Figure 5.3.

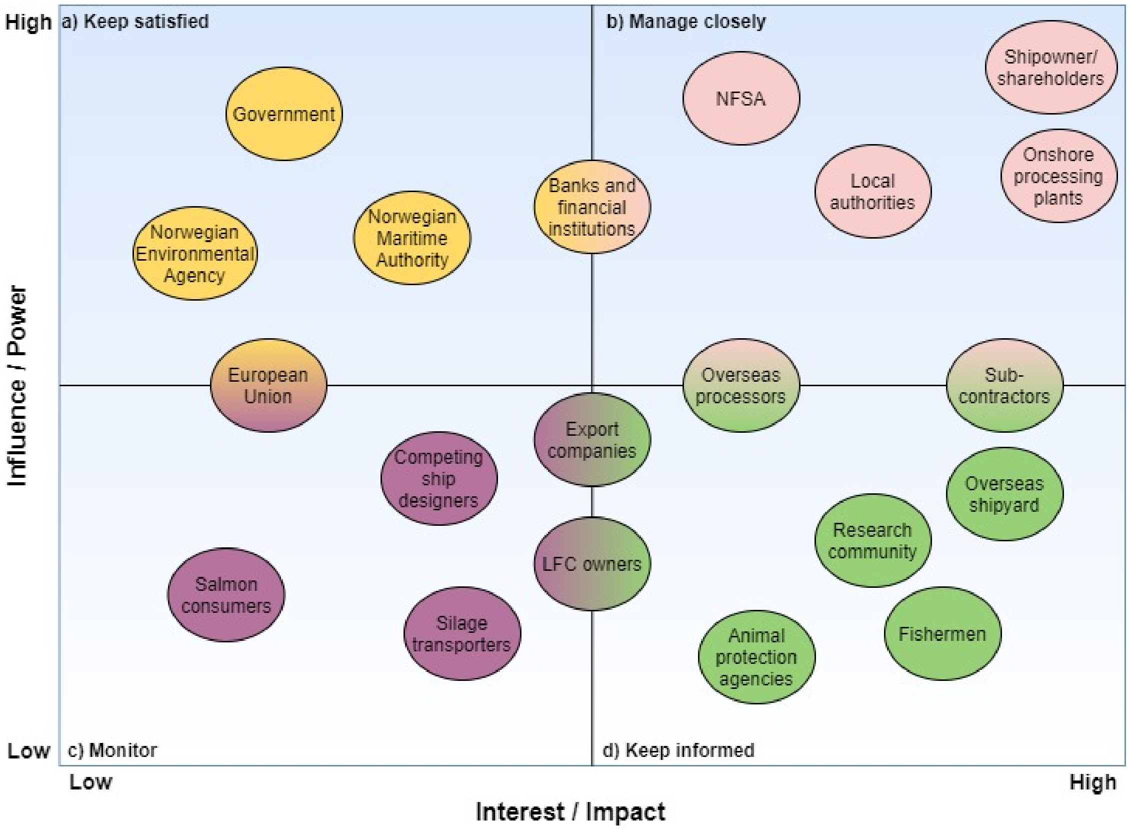


Figure 5.3: Power/Interest matrix resulting from the stakeholder analysis. Stakeholder categories: a) Keep satisfied (top left); b) Manage closely (top right); c) Monitor (bottom left); d) Keep informed (bottom right).

The regulatory body - Those to keep satisfied (a)

The Norwegian government has an interest in supporting its country's aquaculture industry as it creates workplaces and generates wealth for the nation. Regulation has been necessary to obtain sustainable industry growth. The government reserves the right to award licenses for aquaculture farming [132]. Commercial licenses are only awarded through government-controlled concessions, as other considerations regarding the environment and competing coastal interests have to be taken into account. One example of government-initiated programs to stimulate sustainable growth are the Development licenses and the Traffic light system (discussed in Section 3.1).

In the case of the slaughter vessel "Norwegian Gannet", the government played a key role in the concept's realization. The project was supported by government agencies (e.g., the Norwegian Coastal Administration and Enova), as the project had the potential of removing a substantial amount of semitrailers from Norwegian roads and reduction in CO_2 emissions [133]. However, a one-word change in the regulation concerning the quality of fish and fishery products made the process of transporting farmed salmonids directly to market illegal (as discussed in Section 3.3.3). The "Norwegian Gannet" case underlines the importance of being aware of current trends in regulation.

Other relevant government administrative bodies are the Norwegian Maritime Authority (NMA) and the Norwegian Environmental Agency (NEA). The NMA is the administrative and supervisory authority for the work on safety for life, health, the environment, and material values on vessels with Norwegian flag and foreign vessels in Norwegian waters [134]. Regulations vary according to vessel type, length, and size (GT), operational area, cargo capacity, and emissions (to mention some). The regulations impose strict demand requirements upon vessels, affecting the possible design space. NMA regulations are familiar to shipbuilders and designers. Therefore, the requirements imposed by NMA regulations are omitted from this thesis. However, the implications of the requirements found in this thesis have to be evaluated against NMA, and NEA regulation before initiating a concept phase of SBV ship design. Preferably, at the very onset of initiating a design project. Assessments in Section 5.4 of how relevant regulations affect vessel design indicates which NMA rules are most affected.

The outsiders - Those that need to be monitored (c)

Stakeholders that should be monitored include salmon consumers, competing ship designers, and silage vessel shipowners. If salmon processed by SBVs is perceived as of lower quality than the use of LFCs, farmer will be reluctant to use SBVs. The quality perception of SBV salmon in the regulatory body of the EU and independent salmon exporters can also play a key role in the success of SBVs. Silage transporters could experience a decrease in raw material from farmers if SBVs are successful. If so, increased silage transport fees could discourage farmers from using SBV technology.

The dedicated - Those that should be informed (d)

Innovation and studies relating to SBVs should also be monitored, but the research community should be included in SBV projects, if possible, improving the understanding of salmon and SBV interaction. Overseas shipyards, typically constructing a large proportion of the vessel, have to receive information that is crucial for meeting requirements related to construction (the same is valid in relation to system sub-contractors). The Norwegian animal protection agency The Norwegian Animal Protection Alliance is in favor of the use of SBVs, recognized as ”mobile slaughterhouses” by the agency [135]. Cooperation could provide a strong ally, that typically criticizes the industry for lack of focus on fish welfare.

Key beneficiaries - Those that have to be managed closely (b)

The rest of this chapter focuses on identifying requirements that originate with the most important stakeholders, those that have to be managed closely. These include the potential owners of SBVs and the onshore processing plants that receive the salmon. In some cases, such as Mowi ASA, these shareholders are part of one company. The Norwegian Food Safety Authority (NFSA) manages a large portion of Norwegian regulation concerning food safety and animal welfare. Therefore, a particular focus has been placed on the NFSA or instead regulations managed by the agency.

5.2 Shipowner requirements

The most important stakeholder is arguably the customer of an SBV design, the shipowner (or merely the owner). The owner is typically the one that commissions the vessel and is the stakeholder with the most influence over the project's completion. Depending on the owner, he will present a more or less extensive set of requirements. It is with the owner requirement elucidation is most significant as some quantified and specific requirements may be unfounded or perhaps unwarranted (e.g., desires the vessel to be larger than a competitor). Since constructing a vessel takes time, from development to final outfitting, the owner gains knowledge and understanding during the project. A better-informed owner may want to impose new requirements on the vessel. If requirement elucidation is not done to a satisfactory degree early, and throughout the project, the resulting vessel may not meet the new requirements. Owner requirements can be explicit (e.g., keep under 400 GT and a maximum draught of 6.0 meters). However, there are often several implicit, *basic* requirements such as "lower energy consumption than a similar ten-year-old vessel," "ensures high quality of transported salmon," or "is safe to operate."

Even though this thesis does not have a distinct customer in mind, the customer of an SBV can be viewed as a *specific customer* as the market segment in question is served by several companies, using similar products [17]. The individual system used for fish handling operation and machinery in slaughterhouses are relatively standardized equipment. However, designing a vessel without a distinct customer makes the requirement elucidation process more difficult as customer requirements can vary according to, e.g., perceived needs, operational context, and financial situation. Formulating some implicit requirements for the SBV concept, that are assumed shared among shipowners, is possible though.

As indicated in Section 5.1.3, the regulatory agency NFSA manages most of the regulations that concern both fish welfare and food safety. They have the power to revoke licenses to operate or demand that changes made. Therefore, it is reasonable to assume that a shipowner will require that an SBV meets all relevant regulations. Perhaps a more implicit requirement is that the SBV also has to meet regulation put forward by other regulatory agencies, such as the NMA and NEA. Regulation originating from the EU that affects the Norwegian industry is mostly implemented in Norwegian regulations and is assumed not to be of particular importance.

Farmers or shipowners have options when choosing a vessel to meet their salmonid transport requirements. Especially in the case of choosing a system for harvesting salmon (see Figure 5.1). Although the range of services offered by the LFC and the SBV are different, they both serve the functional requirement "transport salmon from production cage to the slaughterhouse." If the cost of the SBV's services is higher than that of the LFC, the SBV is the less attractive option (e.g., the required freight rate is higher for the SBV). The owners of the SBV are potentially independent service companies or transporters and depend on winning contracts with farmers.

A reasonable assumption is that owners will require the system to deliver salmon to slaughterhouses without having to invest in complex and expensive systems on-shore. Also, the system has to deliver a product that has a "good" quality. These requirements are also assumed to be essential for the owners of slaughterhouses. Another assumption is that the slaughterhouses require the SBV to meet their logistical needs. If a slaughterhouse fully incorporates an SBV as its salmon delivery system, it removes the need for waiting-cages. However, the waiting-cages are a logistical advantage (as discussed in Section 3.3.2). Therefore, another slaughterhouse requirement is that an SBV should match the slaughterhouse's daily shift capacity. If a slaughterhouse has a shift capacity of, e.g., 250 tonnes while the SBV has a maximum cargo capacity of 200 tonnes, the slaughterhouse will miss its daily production mark (unless re-supply is possible). Sustainability has become a more frequently used word in the modern Norwegian aquaculture industry. An assumption is that at minimum, the owner demands that the SBV meets current environmental regulation, ensures the safety of its crew, and is an economically sound investment.

Assumed customer requirements for a SBV are as follows (D = demand, W = wish, D/W = borderline demand, but worded in a relative manner):

- The vessel satisfies current national regulation (D)
- Uncertainty of satisfying future national regulation is low (W)
- Required freight rate for harvest transport is lower compared to LFCs (D)
- Slaughtered salmon are of good quality when delivered to the slaughterhouse (D/W)
- The SBV does not imply investing in complex and expensive equipment for the slaughterhouse (W)
- The system should meet the supply need set by the slaughterhouse, i.e., the size of cargo hold is sufficient (W)
- The system is safe to operate (D/W)

These requirements are in their nature, only statements. Developing more refined requirements that are beneficial in further concept development is needed. In cases where there are conflicting interests among the owners, or the importance of the individual perceived need is uncertain, decision-making tools like that of the Analytical hierarchy process (AHP) can be utilized (not in the scope of this thesis). Some specific customer requirements were revealed in conversation with Moen Marin. These requirements are:

1. The RSW system cannot fail while transporting salmon (D)
2. Backup system if main engine fails ("take-me-home" function) (D)
3. Time from the salmon is killed until it has bled out is less than 1.5 minutes (D)
4. The salmon has bled out before reaching RSW storage tanks (D/W)
5. Digital positioning (DP) capability is preferred (W)

6. Processing plant must satisfy the MOWI hygiene manual (D)
7. System meets Tier III IMO Marine engine regulations (D)
8. Vessel has to be approved for operation in UK and EU waters (D)

1. and 2. are requirements of redundancy. Customers have required these as they are perceived as essential needs. SBV's in use today can carry upwards of more than 400 tonnes of dead salmon. In the case of the RSW system or main engine failure, the financial impact of losing the cargo will be disastrous. Requirements related to redundancy is further discussed in Chapter 6. Requirements 3., 4. and 5. are related to quality and will be put more into context in Section 5.3 and 5.4, and further discussed in Chapter 6. Requirement 6. is related to quality and food safety and will be put into context in 5.5. As discussed previously in Chapter 3.4.2 many Norwegian shipowners operate in overseas transport markets. However, as requirements 7. and 8. are not in the scope of this thesis, they are not further discussed in this thesis.

5.3 Quality of delivered salmon

Chapter 4 presented some of the stressors salmon are exposed to, and that emphasized that stress can shorten pre-rigor times, thereby lowering quality. Chapter 3.3.2 briefly discussed the importance of pre-rigor processing since the rigid post-rigor salmon is difficult to handle. This type of quality is an example of *technological* quality [136]. Other technological qualities of fish are the texture of the meat, gaping (tearing of the connective tissue between muscle layers (myomers), causing holes and slits in the fish fillet), and water holding capacity of the fillet. Nutritional quality (the composition of proteins, lipids, vitamins, and more) and sensory quality (e.g., odor, flavor, eating quality) fall outside the scope of this thesis. Hygienic quality is always essential for those handling food, especially highly perishable food items such as fish. Hygienic quality refers to the efforts made to avoid microbial spoilage. Spoilage of fish depends on time, temperature, and microbial flora (amount of bacteria and type of spoilage organism).

Shelf-life and spoilage of fish are closely related to [136]. Shelf-life is defined as the length of time loss of quality loss in processed food is tolerable. Low temperatures and not creating suitable growth environments for microbes is essential for extended shelf-life. RSW or ice will stabilize fish raw material, mainly regarding microbial growth, but it also reduces enzymatic hydrolysis and lipid oxidation (degradation of proteins and lipids, respectively) [137]. Salmon blood is an excellent growth media for several microbes, e.g., Listeria [138]. Listeria is a bacteria that can cause severe infections in humans [139]. In Norway, Atlantic salmon and Rainbow trout are sorted by the quality grades Superior, Ordinary, and Production [140]. Superior is defined as "*a premium product with features that make it suitable for all purposes. The product is without significant defects, damage, or defects and has a positive overall impression.*". Ordinary quality is defined as "*a product with limited external or internal defects, damage or defects. The product shall not have any substantial defects, damages, or deficiencies that would make further application difficult.*". Production grade salmon is defined as "*Fish that do not meet the requirements of Superior or Ordinary due to errors, damage or defects.*". In previous years the share of salmon graded as Superior was as 90-97 % of all processed fish [141]. Based on some reports, this number has decreased overall, being closer to 90 % today [142]. As discussed in Section 3.3.3 production-grade salmon has to be sorted domestically before transported to overseas markets. The amount of non-Superior salmon constitutes around 120 000 tonnes of HOG a year [142]. A standard deduction for salmon of quality grade ordinary is 1.5-2 NOK, and 5 to 15 NOK for production-grade salmon [140].

Ensuring salmon of high as possible quality is essential for economic and food safety reasons. The SBV should have RSW capability of cooling the salmon to a lower temperature than that of LFCs, as the salmon's shelf life is important when dead, not its life. However, freezing should be avoided as thawing can cause gaping [143]. Gaping can also be caused by rough handling, causing physical damage, and subsequent gaping of fillets. Straightening the salmon after rigor occurs can in a similar way cause gaping. Also, a study found that lower temperatures (below -0,5°C) shortened pre-rigor times [144]. Section 3.3.2 explained that international regulation dictates a fish temperature of no more than 2°C during transport. Lowering the slaughtered salmon to at least this temperature onboard poses a logistical and economic improvement for farmers, as it shortens the energy spent and the time necessary for chilling the fish on land. As little blood as possible should be present in the RSW tanks, as this can allow for microbes to grow in the salmon's orifices (e.g., its gills). These assessments lead to the following requirements:

- Gentle loading and unloading (W)
- The system shall be able to deliver pre-rigior salmon (D)
- RSW system can lower salmon temperatures to a range between -0.5°C and 2°C (W)
- Blood is removed from the salmon before it is stored in the RSW tanks (W)

5.4 Governing rules and regulations

Regulation as a driver for development and design in Norwegian aquaculture is well exemplified with the sea cage technology development that came from regulations such as the "NYTEK Regulation" (the regulation does not contain any specific requirements, but refers to the standard NS9415:2009 that does[40]) [39]. Moreover, the development of LFCs has largely been affected by regulations such as the "Regulations on transport of aquaculture animals" [45], requiring closed system technology and indirectly through the "Regulations on salmon lice control" [120] which intensified the combatting of the Salmon louse and subsequently increased the demand of LFCs offering delousing services. It is worth mentioning that rules and regulations are mostly based on perceived needs from the aquaculture industry itself or other stakeholders. Rules and regulations can be viewed as limiting when designing systems, as they to inflict demands. For new designs, they can act as incentives and viewed as a possibility for innovation [145]. As long as the regulations are not characterized by *regulatory capture*, i.e. serving the interest of few interest groups in a discriminate manner. However, in highly uncertain markets regulation can serve as a hindrance for innovation as information asymmetry between existing regulation and developing technology is higher than in more mature (low uncertainty) markets.

The most important law regulating the Norwegian aquaculture industry is the *The Aquaculture Act* and arguably *The Animal Welfare Act* [115], [146]. Additionally the *The Food Act*, relating to food production and food safety is also important to be familiar with as many regulations have their legal basis in it [147]. Regulations related to export of fish have their legal basis in *The Fish Export Act* [148]. The Norwegian Food Safey Authority (NFSA) is a national government agency that helps to ensure safe food and safe water for consumers [149]. The NFSA's role is to prepare proposals for and manage regulations, and provide guidance for these, conduct risk-based supervision, communicate information and knowledge, in addition to emergency preparedness. The most important regulations affecting the SBV concept that NFSA manages are the following:

- The Regulation concerning slaughterhouses, etc. for aquaculture animals (Norwegian short title: Forskrift om slakterier mv. for akvakulturdyr) [81].
- The Regulation concerning aquaculture operation (Norwegian short title: Akvakulturdriftforskriften) [80].
- The Regulation concerning Animalia hygiene (Norwegian short title: Animaliehygieneforskriften) [150].
- The Regulation on quality of fish and fishery products (Norwegian short title: Forskrift om kvalitet på fisk og fiskevarer) [93].
- Internal control regulations to comply with aquaculture legislation (Norwegian short title: IK-Akvakultur) [151].
- The Regulation concerning disinfection of inlet water and wastewater from aquaculture-related activities (Norwegian short title: Forskrift om desinfeksjon av vann, akvakultur) [152].
- The ATP Regulation and Additions to the ATP Regulation (Norwegian short title: ATP-forskriften and Tillegg til ATP-forskriften) [153], [83].

Regulations that have implications for the SBVs concept that NFSA manages are the following:

- The Regulation concerning the transport of aquaculture animals (Norwegian short title: Forskrift om transport av akvakulturdyr) [45].
- The Regulation concerning measures to prevent, limit and combat PD in aquaculture animals (Norwegian short title: Forskrift om tiltak for å forebygge, begrense og bekjempe PD hos akvakulturdyr) [11].
- The Regulation concerning the approval and use of disinfectants in aquaculture facilities and transport units (Norwegian short title: Forskrift om desinfeksjonsmidler, akvakulturanlegg) [154].

- The Regulation concerning the protection of salmon stocks (Norwegian short title: Forskrift om beskyttelse av laksebestander) [155].
- The Regulation concerning the killing of animals (Norwegian short title: Forskrift om avliving av dyr) [156]

Many of the following statements related to systems and methods used in slaughtering facilities are from the manual *Guidance on requirements for good fish welfare at the slaughterhouse for aquaculture animals*, provided by the NFSA. [97].

5.4.1 General requirements for a slaughtering facility

According to NFSA the most central regulation for those operating a process or slaughtering facility is "The Regulation concerning slaughterhouses, etc. for aquaculture animals" (Slaughterhouse regulation) [97]. The facility must be approved according to the regulation and the slaughtering process itself (from crowding, pumping an until properly killed) is also governed by this regulation. According to NFSA all vessels and mobile units that kill and stun fish are defined as "mobile slaughterhouses" and must therefore abide by the Slaughterhouse regulation [157]. Requirements set by the regulation are not typically specific in what has to be done in order to preserve good animal welfare [97]. In other words, the goals of the requirements are stated rather that how to get there. The "sensibility" or "responsibility requirement" ("Forsvarlighetskravet" in Norwegian) is a central concept as the word "sensible/responsible" is used frequently in the regulation (e.g. "sedation should be carried out in a sensible manner."). The intention is to motivate for "good practice" behavior (act with care and integrity) as opposed to "negative culture" behavior, e.g. behavior that can arise unconsciously when believing the fish does not feel pain.

Regulation: Technical applications have to be suitable concerning fish welfare. New methods and technical applications have had to be tested and found acceptable before they are put into use. They also have to work in practice, not only shown that they *can* work. However, the documentation of the method or the science behind the method (e.g., percussion as a stunning method) is more important than the specific equipment used (e.g., a new percussion machine) [97]. The NFSA considers documentation of methods and systems related to **sedation**, **anesthesia** and **killing** to be of particular importance.

Assessment: The requirement for being able to document that the methods and systems used onboard are suitable for use concerning fish welfare implies that only established methods are and predominantly existing technology is of interest. The requirement limits the design space in that wild conceptual ideas that are plausible but not documented, can make the success of the design too uncertain. The wording of the requirement also implies that the use of methods and technical applications can be banned by the NFSA if they are no longer suitable concerning fish welfare. Bans have happened in the industry before. The use of CO_2 was banned in 2007 as an anesthetic [158], and replaced by electrification or percussion stunning machines. Therefore, being aware of the future uncertainty of fish interacted systems related to fish welfare is important.

Regulation: The salmon must be killed as soon as possible after arriving at the processing plant (related to fish welfare) and no more salmon than which is sensible is to be killed per time unit. The pace of the slaughtering process must be set at a speed that allows for validating the anesthesia and death of all salmon, and so that the salmon does not ”pile up” at any one point in the process.

Assessment: This potentially puts a constrain on the efficiency of the vessel. It is important that the loading speed is not too slow as: 1) The crowding time of the fish still in the net cage is likely to stress or injure the salmon (i.e. poorer fish welfare and lower quality); 2) The quality of the salmon will deteriorate from the moment it is killed. If the speed is too high validation of anesthesia and death of the salmon may be impossible. The speed range of the loading system has to allow for adjusting to the particular situation. More loading tubes and pumps could increase the efficiency and be in line with the aforementioned requirements. Subsequently the number of slaughtering lines would have to increase, the thereby increase the size of the vessel. The flow of salmon, from loading to storage, has to be continuous from the time it enters the vessel (salmon that is stationary after being anesthetized, before being killed, could wake up). Validation of each individual, regarding state of anesthesia and alive or dead, can also affect efficiency.

At this point several general requirement statements can be made and subdivided into major systems. Further subdivision, development and refinement is necessary in order to map from the functional domain to the physical domain. Identified requirements (D = demand, W = wish/perceived need, D/W = borderline demand, but worded in a relative manner):

- Loading system:
  - Equipment and methods used have to be documented that they are suitable with respect to fish welfare (D)
  - Uncertainty of the systems appliance to future fish welfare regulation has to be low (W)
  - The speed of the loading process can not cause unnecessary pain, suffering and fear to the salmon (D/W)
- Processing plant:
  - Systems and methods that are used have to be documented that they are suitable with respect to fish welfare (D)
  - Uncertainty of the systems appliance to future fish welfare regulation has to be low (W)
  - The speed of the slaughtering process can not cause unnecessary pain, suffering and fear to the salmon (D/W)
  - The condition (i.e. live or dead, anesthetized or not) of each individual salmon has to be controlled (D)

5.4.2 Requirements related to specific operations and systems

Regulation: The number of crowding operations should be limited to a minimum, as all crowding operation can lead to panic and stress in the salmon. All salmon that is already crowded should be processed. Responsible execution of a crowding operation varies according to local conditions, sea water temperature, the health situation of the salmon etc. Increased densities and prolonged periods of crowding is associated with increased levels of stress. In a report from the Norwegian Veterinary Institute (NVI) in 2009, researchers provided a description of how the activity within a net cage can give an indication of the degree of crowding, as seen in Figure 5.4 [72]. At the target level (5.4a) salmon are swimming calm, not necessarily in the same direction, while level 2 (5.4b) is still considered good and there is normal activity at the pump's intake. Level 3 (5.4c) is unwanted and the salmon is characterized by hectic behavior, breaking the surface and white sides of the fish are visible. Unacceptable levels (5.4d) of crowding is characterized by very high activity, salmon are gaping for air. Due to exhaustion, the activity will decrease over time. At level 4 a steady loading rate is not possible. In the extreme scenario (5.4e) the salmon is exhausted and will die if not given space. Several salmon are floating on the surface. During crowding operations the oxygen levels are to be measured, unless crowding operations last less than 30 minutes at sea water temperatures of less than 6 °C [80]. An acceptable minimum oxygen saturation is 70-80 % [72]. Lower sea water temperatures allow for somewhat lower oxygen saturation, while it should be higher at temperatures up towards 20 °C.

(a) Level 1 (Target)

(b) Level 2 (Satisfactory)

(c) Level 3 (Unwanted)

(d) Level 4 (Unacceptable)

(e) Level 5 (Extreme)

Figure 5.4: Levels of crowding from Level 1 (target) to Level 5 (extreme) [72].

Assessment: It is of particular importance for a SBV that the salmon experiences as little stress as possible as the longest possible pre-rigor time is desirable. The same regulations related to fish welfare applies to LFCs but is has been shown that the salmon typically will recover from a stressful crowding operation while transported in the LFCs wells (see Figure 3.15). Additionally, long-term stress can cause the salmon to loose skin mucous, and subsequently scale loss. This can cause a degradation in quality and price as discussed in Section 5.3. The loading system has to be able to function efficiently without reaching level 3 crowding degree. The SBV should be able to perform crowding operation independent of methods used or equipment available at production sites. Oxygen levels have to be measured and if possible regulated during crowding.

Regulation: Pumping of live fish is to be done in a gentle manner and in at a sensible pace, to avoid inflicting injury and unnecessary strain. Fish should be taken out of the water to the minimum extent possible. The pumping distance is to be as small as possible and suction head, pressure and discharge height is to be regulated so that they do not cause injury. As discussed in Chapter 4 farmed salmons' heart and circulatory system is vulnerable to high pressure, particularly when weakened due to diseases that affects the heart (e.g. CMS).

Assessment: Systems that allow for minimum time out of water are favorable to those that do not. The loading system should be positioned as close to the fish cage as possible to avoid unnecessary suction head and the system should allow for minimum pressure change. Placing of the system should allow for a short traveling distance. The positioning has to be optimized and will has to take into account the layout of the processing plant and vice versa. In addition, depending on the lifting system the distance from its power source has to be taken into account, e.g., using a hydraulic system where a pump with a motor is driven by hydraulic fluid from a hydraulic pump. In this case the hydraulic motor will have to be connected to the hydraulic system via pipes.

Regulation: The fish tubes the salmon are to travel alive through have to be dimensioned according to the amount and size of the fish to achieve an even flow. If the salmon is stationary within the tubes there is a risk of oxygen falling to levels that imposes a risk of salmon dying. A rule of thumb is that a salmon consumes 0.5 liters of oxygen every minute. The layout of the tubes is to be made in such a manner that it imposes minimal risk of injury to the salmon. It is important that the internal surface of the fish tubes are smooth. Seams are particularly important to pay attention to. The tubes should bend with large curves to avoid that the salmon does not collide with the tube walls. An example of a bend in a fish tube can be seen in Figure 5.5 [159]. At the outlet of the tubing system the salmon should not be exposed to large drop-heights without surrounding water.

Figure 5.5: Bend inside a rigid part of a fish tube [159].

Assessment: Metal tubes that are used within the vessel should be of a dimension large enough to ensure welfare for the largest category fish that the vessel intends to load. Larger tubes will require more space within the vessel and the capacity of the pump will have to be sized according to the flow of water. Minimal amount of bends is preferable as this will require less space and in compliance with the requirement for shortest possible distance travelled. A large vertical distance between the lifting device (e.g. pump) and the outlet is unwanted as the tube(s) will have to bend at a wider angle (e.g. the pump is located on the main deck and the processing plant on a lower deck). Placing the processing plant on the main deck would be an efficient way of avoiding bends. This has to be accounted for in stability calculation, as the weight of the plant will affect the vessel's center of gravity. To protect machinery, personnel and electronics the use of a shelter deck seems unavoidable. This may affect the overall enclosed volume space of the vessel, and subsequently the gross tonnage (GT).

Regulation: The fish is to be anesthetized before, or at the same time, it is killed and is to remain anesthetized until death occurs. The NFSA assesses that it is possible to achieve this for 100 % of the processed salmon, given that the slaughtering pace is adjusted correctly and enough personnel to verify the level of anesthesia is available. The method used must cause immediate anesthesia, but: The salmon is not to experience unnecessary pain and stress. 0.5 seconds is considered immediate. If necessary, the salmon must be sedated or immobilized before anesthesia. The salmon must die from loss of blood to the brain, and it's death verified before initiating further processing. Fish have brain activity a while after the brain's blood supply is lost. Therefore, the anesthesia has to last a while and preferably be irreversible.

Assessment: The chosen method for anesthesia and the machinery used has to be documented and demonstrated that it causes full anesthesia within 0.5 seconds. If the NFSA assesses it to be possible for 100 % of the salmon to be anesthetized until death occurs, enforcement may be more strict in the future. Anesthesia method, machinery, and machinery arrangement must take precedence over other requirements in order to best meet this target. It is worth exploring the possibility of using redundancy in this part of the processing plant in order to 1) ensure 100 % of salmon anaesthetization before death; 2) the possibility of removing manual verification, as this potentially crew member. The killing method should allow for efficient bleeding, causing quick exsanguination (bleed out till death). A method that anesthetizes and kills at the same time is worth exploring, as this could potentially save space, but the method must meet fish welfare and other requirements stated above. Choice of method is further discussed in Section 6.3.2.

The assessment for what regulation related operations and system leads to the following requirements identified:

- Loading system:
  - The loading system can not require higher net cage crowding degree than level 2 (as seen in Figure 5.4b) (D/W)
  - The SBV should have the necessary equipment for crowding, independent of production sites (W)
  - Oxygen levels in the cage have to be measured during crowding (D)
  - Regulation of the oxygen levels during crowding is desirable (W)
  - All loading components allow for minimum time out of water for the salmon (W)
  - As low suction head as possible (W)
  - Minimal pressure change throughout the loading system (W)
  - Short transport distance from inlet to outlet (W)
  - Placing of the lifting device (e.g., a pump) should not be affected by the placing of its prime mover (W)
  - Tubes have to be large enough to ensure welfare of the salmon (D)
  - Avoid dropping fish transferred to the processing plant (W)
  - Limit the amount of bending of the fish tubes going from the net cage to the processing plant (W)
- Processing plant
  - The anesthesia method and the machinery must cause full anesthesia within 0.5 seconds (D)
  - Anesthesia method should keep 100 % of salmon individuals anesthetized before death occurs (D/W)
  - The killing method should allow for effective bleeding (W)
  - A method that anesthetizes and kills at the same time (W)
  - The plant should be inside a superstructure (W)

Internal control and ease of maintenance

Regulation: In addition to the aforementioned general requirements and requirements concerning operations and systems, the manual from NFSA calls for "employees to have the necessary competence concerning fish welfare" [97]. Furthermore, that the employees to have "the ability to maintain and operate machinery so that it functions in a welfare wise sound manner." Maintenance is several times emphasized as being of importance as machinery that works poorly can cause poor fish welfare (e.g. killing/bleeding device that misses its mark on the salmon).

Assessment: The demand of having properly trained personnel does not affect the design of the vessel or the processing plant onboard directly. However, personnel have to have the proper qualifications to be able to judge fish welfare indicators and to perform maintenance. Choice of machinery that is able to detect welfare indicators and confirm anesthesia and death is preferable, as it could allow for less manpower in the processing plant. In a larger SBV this could mean reduction in crew (lower OPEX) and less need for accommodation space. Maintenance of fish handling systems should be easy to maintain and durable. This implies the following requirements:

- Processing plant:
  - Monitoring system that can confirm anesthesia and death of salmon (W)
  - Enable simple maintenance of machinery in process plant (W)
  - Systems have long maintenance intervals (W)

5.5 Company standards

Not all demand requirements originate from government regulation. Many companies and interest groups have developed own standards with rules not necessarily incorporated into laws. A product that does not adhere to standards may end up a less attractive option to those that do when competing in the same market for the same type of customer. For example, Company A has experience within the field of salmon transportation and can guarantee that 99.9 % of the salmon transported will not be downgraded in quality as a result of their handling. They follow all regulations but have a company standard that ensures a good result. Company B also follows regulation, but do not use a particular standard. They can guarantee that 97.5 % will not be downgraded. Unless the expense for the service of company B is demonstratively less than A's, the customer will choose A, if left with a choice.

Specific company standards are not discussed in this thesis, but the fact that they exist validate their mention. While industry standards (e.g., NS 9417:2012 on salmon an trout farming terminology [160]) are publicly accessible, companies own the right to distribute company standards. If a standard describes methods that give a company an edge over its competitors, willingness to share information is understandably reduced. Mowi ASA uses a strict hygienic manual for processing plants (describing both methods and design layouts are) [161]. SBV owners and designers have to be aware of company standards, such as the MOWI hygiene manual, especially if the SBV will service multiple farmers, as this implies multiple company standards.

5.6 Requirements list

To sum up the following requirement statements identified are:

Owner and quality requirements

- Required freight rate for harvest transport is lower compared to LFCs (D)
- The SBV does not imply investing in complex and expensive equipment for the slaughterhouse (W)
- The system should meet the supply need set by the slaughterhouse (W)
- The system is safe to operate (D/W)
- The RSW system cannot fail while transporting salmon (D)
- Backup system if main engine fails ("take-me-home" function) (D)
- RSW system can lower salmon temperatures to a range between -0.5°C and 2°C (W)
- Blood is removed from the salmon before it is stored in the RSW tanks (W)
- The system shall be able to deliver pre-rigior salmon (D)

Requirements for loading system

- Equipment and methods that are used have to be documented that they are suitable with respect to fish welfare (D)
- Uncertainty of the systems appliance to future fish welfare regulation has to be low (W)
- The speed of the loading process can not cause unnecessary pain, suffering and fear to the salmon (D/W)
- The speed of the loading process must allow for maximizing the pre-riogor time of the dead salmon (W)
- The loading system can not require higher net cage crowding degree than level 2 (D/W)
- The SBV should have the necessary equipment for crowding, independent of production sites (W)
- Oxygen levels in the cage have to be measured during crowding (D)
- Regulation of the oxygen levels during crowding is desirable (W)
- All loading components allow for minimum time out of water for the salmon (W)
- As low suction head as possible (W)
- Minimal pressure change throughout the loading system (W)

- Short transport distance from inlet to outlet (W)
- Placing of the lifting device (e.g. a pump) should not be affected by the placing of its prime mover (W)
- Tubes have to be large enough to ensure welfare of the salmon (D)
- Avoid dropping fish transferred to the processing plant (W)
- Limit the amount of bending of the fish tubes going from the net cage to the processing plant (W)

Requirements for onboard processing plant

- Systems and methods that are used have to be documented that they are suitable with respect to fish welfare (D)
- The speed of the slaughtering process can not cause unnecessary pain, suffering and fear to the salmon (D/W)
- The condition (i.e. live or dead, anesthetized or not) of each individual salmon has to be controlled (D)
- The anesthesia method and the machinery must cause full anesthesia within 0.5 seconds (D)
- Anesthesia method should keep 100 % of salmon individuals anesthetized before death occurs (D/W)
- The killing method should allow for effective bleeding (W)
- A method that anesthetizes and kills at the same time (W)
- The plant should be inside a superstructure (W)
- Monitoring system that can confirm anesthesia and death of salmon (W)
- Enable simple maintenance of machinery in process plant (W)
- Systems have long maintenance intervals (W)

The following chapter describes the SBV as a system, and further refines the requirements in the list.

6 The stun-and-bleed vessel (SBV)

This chapter presents the stun-and-bleed vessel (SBV) and its technology onboard, focusing on the payload, or mission-related systems (described in Section 2.1). First, a short background of how technology has developed is examined. The requirements list from Section 5.6 forms the basis for evaluating the use of stun and bleed technology in possible modes of operation in chapter 7. Also, this chapter proposes a grouping of SBV types and suggests a clarification and use of terminology.

Killing salmon before reaching a processing plant was briefly mentioned in Section 3.2 as a standard harvesting method in Norway in the early days of salmon farming. By the time specialized LFCs made their entry in the 1980s, the practice of killing salmon on site phased out. Killing salmon at the harvest site was considered to be a more significant disease risk than LFCs, and less effective with systems available at the time. A UK study from 2003 evaluated the relative risk for transmission of the Infectious salmon anemia virus (ISAV) using eight different harvesting methods [57]. The eight methods in the study can be seen in Figure 6.1 (M1-M8). The study concluded that the method of towing cages from production sites to processing plant was the method that would most likely spread ISAV (M8). Other methods considered were the use of well-boats (LFCs) to transport live fish (M6-M7) and to kill the salmon onboard an LFC, boat, or barge (M1-M5).

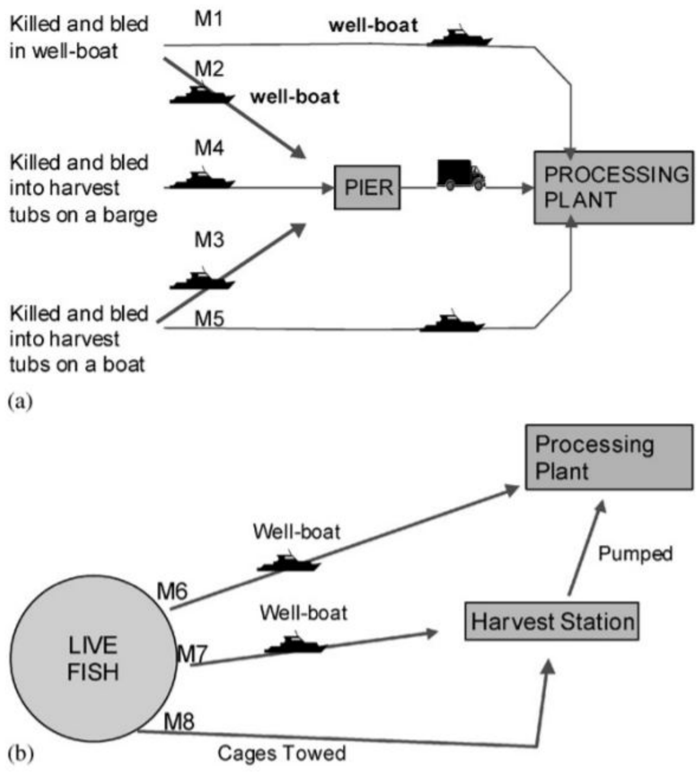


Figure 6.1: Eight harvest methods evaluated by by their risk of spreading Infectious salmon anemia virus (ISAV). (a) Harvest methods involving the transport of dead fish. (b) Harvest methods involving the transport of live fish [57].

Utilizing a "harvest station" (equivalent to waiting-cage) and LFC combination (M7) was found to have the highest probability of transmitting ISAV to farms in the vicinity of the processing plant. In poor weather, M6 (direct-unloading from LFC to a slaughterhouse) and M7 posed a high risk of transmitting ISAV to farms en route to the slaughterhouse (only M8 had a higher risk). Towing was the most probable method for transmitting the disease to neighboring farms during harvest, but the methods that involved killing the salmon onboard (M1-M5) were all considered to pose significant risks of ISAV transmission. The main reason for this was the risk of losing fish overboard during slaughtering operations, assuming the killing table used was positioned on an open deck. These escaped salmon could potentially spread the disease to other fish in the area.

The risk of losing fish overboard during loading due to an open deck underlines the assessment for the requirement of a shelter deck, pointed out in Section 5.4.2. In the mid-2000s, companies were again researching the idea of killing salmon on board a vessel, instead of using SBV. Killing salmon on site is a standard practice used in modern Canadian salmon farming, and Norwegian companies identified that modern vessels could have advantages such as capacity, cost, quality, fish welfare, and bio-security [162]. The companies quickly realized that the new vessel type should only transport harvest fish, as unsatisfactory cleaned RWS tanks (with salmon blood and mucus) would pose a health risk to living fish, e.g., smolts. In 2008 Napier became the first Norwegian shipowner to utilize the vessel type [13]. The independent research organization Nofima AS was closely involved in developing the vessel from 2006, while Mowi ASA was involved in the project from the start.

Mowi ASA stated in their annual report of 2018 that 100 % of salmon form Mowi Norway South will be harvested at the farm, indicating no more use of LFCs for downstream transport of fish [161]. One reason for Mowi ASA to make this transition is that the company expects stricter transport regulations in the future. Other Norwegian companies have invested in new harvest vessels that utilize stun and bleed technology [163], [164]. Newly constructed vessels are also finding their way into overseas markets such as Canada, the UK, and Tasmania [165], [166]. A selection of modern SBVs is shown in Figure 6.2 [166], [167], [165].

Figure 6.2: A selection of modern stun-and-bleed vessels (SBVs). From top left corner: "Emmanuel", "Elax Mist", "Geemia Joye", "Aqua Merdø" (image source: Frode Adolfsen).

6.1 Grouping of SBVs

Section 5.1 presented the two main salmon transport requirement categories a Stun-and-bleed vessels (SBVs) can meet, illustrated in Figure 5.1. These were the transport of harvest salmon and transport of salmon that has to be prematurely harvested, due to different causes (such as disease or weakened after treatment). The way a harvest vessel is can define it. Today there are several smaller SBVs in use and under construction. These vessels have, in some cases, significantly smaller cargo capacity than other SBVs. Their main intended use is in an emergency support role, e.g., in delousing operations where salmon mortality increases. After some operations were the salmon is physically handled, e.g., during delousing operations, relatively many individuals will die as a result of fatigue or injury (particularly if the salmon is already weak from disease). Fish that are dead before harvest are unsuitable human consumption, and illegal to cell as such [93]. If these fish are processed before death occurs, a large quantity of otherwise lost biomass could be used for human consumption. More on this subject can be found in Section 7.2.

Section 3.3.2 discussed the logistical issue of SBVs having to meet the shift capacity or daily production capacity of slaughterhouses. This is is especially the case for slaughterhouses that only received salmon from SBVs, or for those that have removed the waiting-cages. Therefore, SBVs may also be defined by their size. The largest slaughterhouse in Norway as of March 2020 is Salmar AS' InnovaMar facility, with a shift capacity of 320 tonnes [2]. Of the 43 slaughterhouses in operation in 2018, only nine facilities had a shift capacity of 200 tonnes or more. Therefore, this thesis defines as large SBV as a vessel with a cargo capacity of 200 tonnes salmon or more. Many of the emergency type SBVs have cargo capacities of approximately 40 tonnes. The slaughterhouse with the lowest shift capacity of a slaughterhouse in 2018 was 40 tonnes. Therefore, this thesis defines a medium SBV as a vessel with a cargo capacity between 40 and 200 tonnes of salmon. Figure 6.3 illustrates the division of these main SBV types.

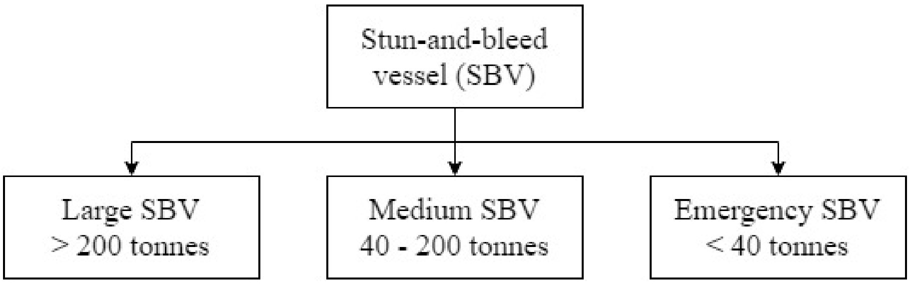


Figure 6.3: Stun-and-bleed vessel (SBV) classification based on operational mode and cargo capacity.

Medium and large SBVs are mainly indented for slaughter operations. However, smaller medium SBVs could be of use as the main harvesting vessel by most slaughterhouses and used as emergency SBVs, in cases where farmers expect high levels of treatment mortality. Larger SBVs are best suited as a main harvesting vessel for the largest slaughterhouses but can also be beneficial as an emergency SBV in cases where sudden and extreme mortality occurs (e.g., with algae blooms like that of the one in May 2019 in northern Norway). A more detailed description of the different SBV types is found in Chapter 7.

A live fish carrier is a volume-critical ship, due to the size of its cargo tanks. An SBV is somewhere in between being volume and area-critical [168]. One advantage of the SBV is that it can store fish more densely in its tanks, than an LFC, but the onboard processing plant requires deck area space. The difference becomes apparent when comparing the RSW tank capacity (cargo volume) versus gross tonnage (GT) of an LFC and an SBV. Figure 6.4 shows the RSW volume to GT relationship for some existing Norwegian SBVs. The figure is comparable to the LFCs' RSW to GT relationship presented in Figure 3.16. LFCs have a GT to RSW relationship of approximately 1:1. At best, the relationship for SBVs is 1:2 in favor of GT. "Aqua Merdø" has a much more significant relationship in favor of GT versus RSW, compared to other SBVs. The reason for the difference is uncertain, and the small number of vessels makes the data statistically insignificant. The GT of a vessel has implications on which regulations a vessel has to follow (discussed in Section 5.1.3) and economy. The question of economy is further discussed in Section 7.1.1.

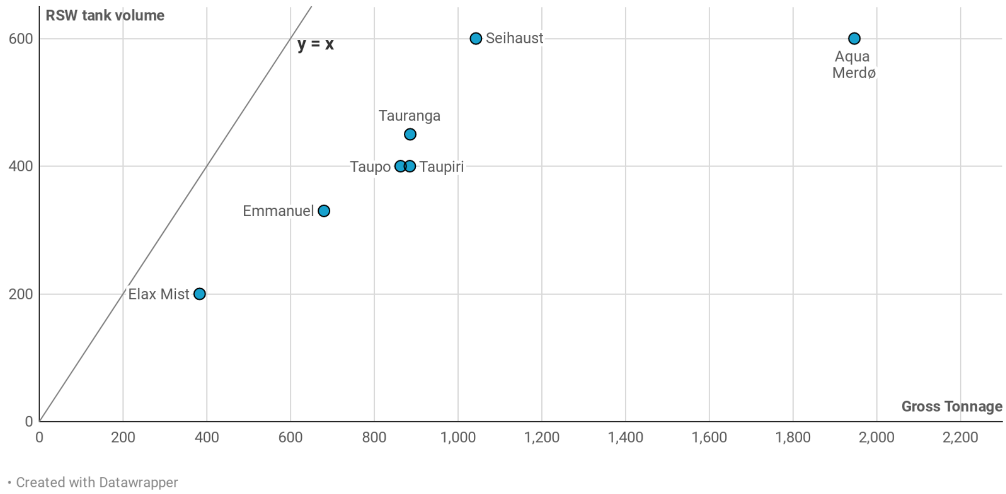


Figure 6.4: Stun-and-bleed vessel (SBV) cargo capacity in RSW tank volume [m^3] versus gross tonnage (GT).

6.2 Functional requirements of an SBV

Using an SBV entails that the slaughterhouse has moved parts of its processing line on board a vessel (as illustrated in Figure 3.3.2 and 3.14). Figure 6.5 outlines the main processes before harvest, onboard the SBV and after the salmon leaves the vessel. SBVs only handle alive salmon once; during the loading process. However, waiting-cages are removed, and the slaughterhouse has to support the direct-unloading of salmon.

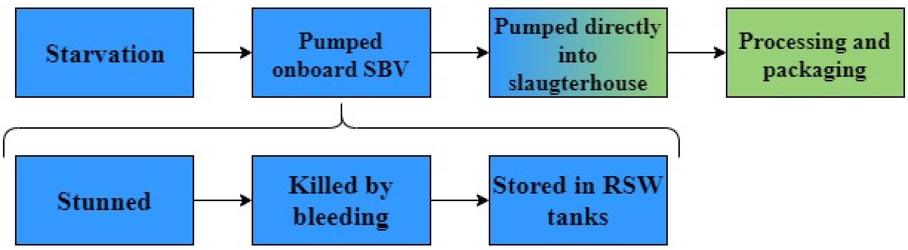


Figure 6.5: Basic steps in a harvest process using a stun-and-bleed vessel (SBV). Blue indicates processes carried out at sea.

The requirements from Chapter 5 have to be evaluated against a physical system. Therefore, a description of the systems needed to support the steps in Figure 6.5 is warranted. The steps can be broken down into consecutive functions, and the requirements from Section 5.6 can be put more into a system context. In the context of functions the requirements are called *functional requirements* (FRs). The functions and functional requirements for the SBV are:

1. Load fish from waiting cage
   (a) The speed of the loading process can not cause unnecessary pain, suffering and fear to the salmon (D/W)
   (b) The loading system can not require higher net cage crowding degree than level 2 (D/W)

   (c) The SBV should have the necessary equipment for crowding, independent of production sites (W)
   (d) Oxygen levels in the cage have to be measured during crowding (D)
   (e) Regulation of the oxygen levels during crowding is desirable (W)
   (f) As low suction head as possible (W)
   (g) Placing of the lifting device (e.g. a pump) should not be affected by the placing of its prime mover (W)
   (h) Count the number of fish (W)

2. Transport fish from loading inlet to processing plant
   (a) Short transport distance from inlet to outlet (W)
   (b) Limit the amount of bending of the fish tubes going from the net cage to the processing plant (W)
   (c) All loading components allow for minimum time out of water for the salmon (W)
   (d) Minimal pressure change throughout the loading system (W)
   (e) Tubes have to be large enough to ensure welfare of the salmon (D)
   (f) Avoid dropping fish transferred to the processing plant (W)

3. Separate fish from unwanted elements
   (a) Separate fish and seawater (W)
   (b) Separate out cleanerfish (D)

4. Stun fish
   (a) The anesthesia method and the machinery must cause full anesthesia within 0.5 seconds (D)
   (b) Anesthesia method should keep 100 % of salmon individuals anesthetized before death occurs (D/W)
   (c) Monitoring system that can confirm anesthesia (W)
   (d) The anesthetized condition of each individual salmon has to be controlled (D)

5. Kill fish
   (a) The killing method should allow for effective bleeding (W)
   (b) Cuts should not cause degradation to quality (W)
   (c) Monitoring system that can confirm death (W)
   (d) The death of each individual salmon has to be controlled (D)

6. Remove blood
   (a) Blood is removed from the salmon before it is stored in the RSW tanks (W)

7. Store fish
   (a) The system should meet the supply need set by the slaughterhouse, i.e., the size of cargo hold is sufficient (W)
8. Chill fish during storage
   (a) The RSW system cannot fail while transporting salmon (D)
   (b) RSW system can lower salmon temperatures to a range between -0.5°C and 2°C (W)
9. Unload fish from vessel to shore
   (a) The SBV does not imply investing in complex and expensive equipment for the slaughterhouse (W)
   (b) Gentle unloading (W)
10. Dispose of wastewater (D)
11. Disinfect the vessel (D)

Counting salmon loaded into LFCs, using a fish counter, is standard on modern LFCs. A fish counter allows for the estimation of loaded biomass, which is essential for an SBV as the payload should match the intended slaughterhouse's shift capacity. Therefore, the functional requirement (FR) "count the fish" (1h) is added to the FR list as a wish. Separating seawater from the salmon (FR 3a in the list) has to be done for some SBVs, depending on the choice of slaughtering machinery (see Section 6.3.2 for more details). By law, cleanerfish have the same rights to fish welfare as that of salmon [115], [97]. The fish has to be killed according to the same regulation as salmon, but the cleanerfish should not be stored in the RSW tanks. Storing cleanerfish in the RSW tanks will unnecessarily use space and chilling capacity and have to be sorted out at the slaughterhouse. Therefore, sorting out cleanerfish upon entering the SBV is added as FR 3b.

The functions "dispose of wastewater" (10. in the list) and "Disinfect the vessel" (11. in the list) have been added as requirements. Waste water from the onboard slaughtering process has to be removed and handled, and disinfection of the plant itself has to meet regulatory standards (See Section 6.3.4 for more details). Overall requirements presented in Section 5.6 not seen in the functional requirements list still have to be taken into consideration. See Section 7.1 for a evaluation of an SBV against the requirements. The following section some mission-related system types that are standard as of 2020. A description of these systems makes benefits the mapping between the functional requirements and physical systems that meet these.

6.3 Mission-related systems

Typical mission-related systems onboard an SBV can be seen in Figure 6.6. The structure of the figure is based on [169] and [20]. The mission-related systems are divided into four main sub-systems; The loading & unloading system, the processing plant, the RSW system, and the hygienic system. The following sections describe some of the equipment used in these sub-systems. As discussed in Section 5.1.3, regulation concerning shipbuilding is not part of the scope of this thesis. Therefore, ship systems such as propulsion machinery, hull, hydraulics, ballast systems, life-saving equipment, and anchoring are not described here.

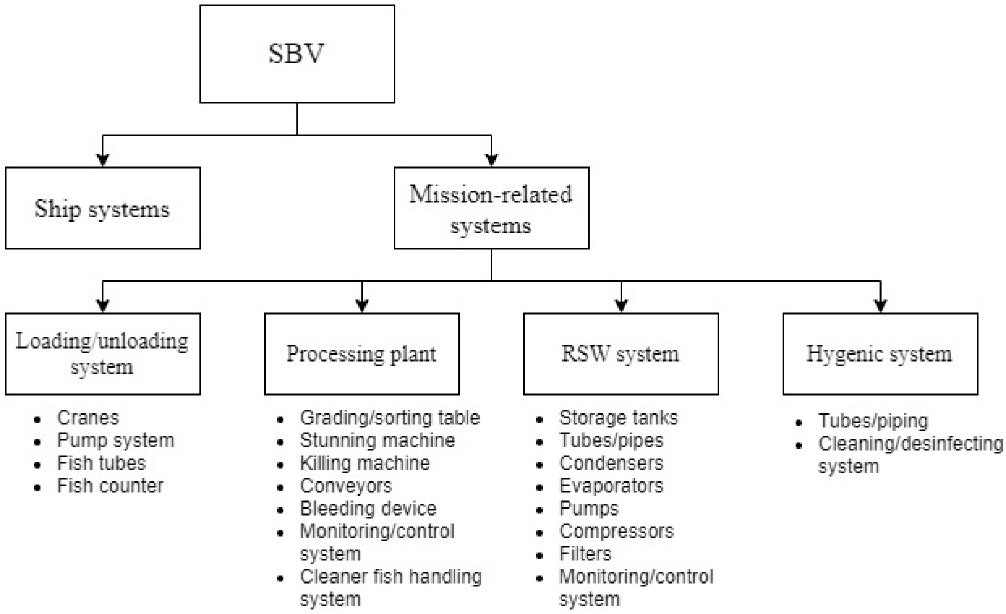


Figure 6.6: Stun-and-bleed vessel (SBV) mission-related systems and sub-systems.

6.3.1 Loading and unloading system

Several procedures can, during the loading phase, increase the stress levels of fish. These include netting, crowding, change of environment and water quality, and temporary extraction from water [170], [171]. Transferal of fish from the water into a ship can and has been done in several ways, using lifting nets (wet-nets), Archimedes's screw principle and pumps [49]. Most commonly, the fish is pumped onboard the vessel in loading tubes (fish tubes). Several pump types and configurations exist. All pumps create a similar effect on the fish in the production cage, sucking water out of the cage through a fish tube (see Figure 6.7). Fish will try to swim away from the point of suction. An approaching net wall hinders the fish from doing so, pushing the fish towards the tube inlet (also known as crowding).

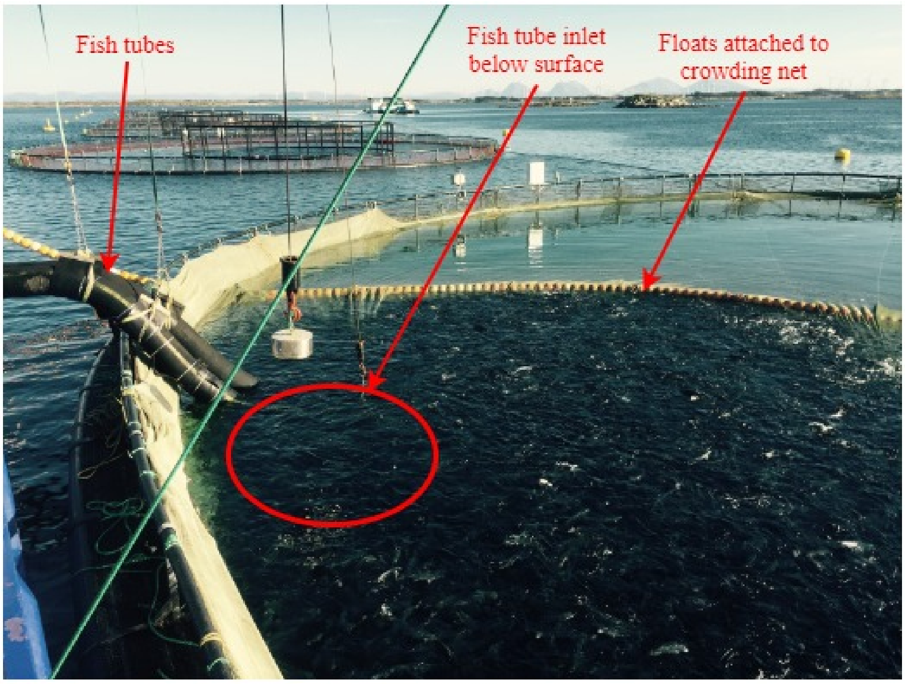


Figure 6.7: Live fish carrier (LFC) loading salmon from a production cage. The inlet is below the surface to avoid mixing of air and inlet water. The density within the cage is increased as the crowding net is pulled closer towards the wellboat [95].

To obtain efficient crowding and be able to perform crowding operations independently, the SBV needs cranes to lift the net. It is not uncommon to use 3-4 cranes during crowding operations, often with the support of service vessels [172]. Four cranes on the deck of an SBV will have severe impacts on other ship systems and capabilities, e.g., power, hydraulic system, and seaworthiness. This interdependency will have to be taken into consideration when designing an SBV. Most production sites have service vessels on hand, with at least one crane. These can be utilized during crowding, effectively becoming part of the SBVs loading system.

Behaviorally targeted methods that can load fish without increasing stress are under development [173]. The new methods could be beneficial for fish welfare for a system such as the SBV, where fish can not recover from stress before being killed. With the use of LFCs, the fish will typically recover during the transportation phase, and the most significant stress impact happens during crowding and pumping from waiting-cage to the slaughterhouse, as seen in Figure 3.15. A Nofima study from 2009 found

that the pumping height on the vacuum side of a vacuum pump is more important than the pressure side for fish welfare[72]. The loading tube inlet must be as low as possible. The fish should never be higher than the vacuum side of the pump during loading. The fish moves from the production cage due to the suction created in a vacuum tank (see Figure 6.8) [174]. Water and fish slide into the tank, and pressure switches from lower than atmosphere to an over-pressure. The overpressure pushes the water and the fish out of the tank.

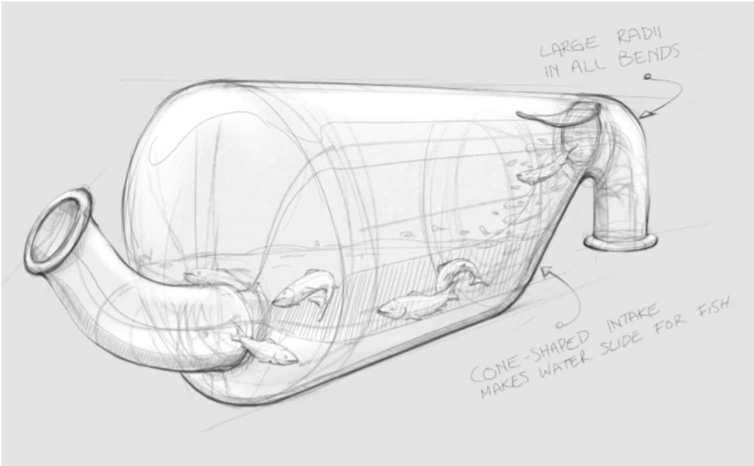


Figure 6.8: Illustration of a vacuum tank from. Inlet and suction side is to the right.

The fish experiences the most stress while moving through the vacuum tank itself, moving from vacuum to pressure side [12]. A remedy for these issues is to implement more than one vacuum tank and pump. In a system with two tanks working in tandem with one common inlet, the inlet side is under close to continuous suction. Continuous flow is possible using three tanks; one filling water and fish from the inlet, one pushing water and fish out, and one being vacuum primed (venting out pressure). The three-step cycle is illustrated in Figure 6.9.

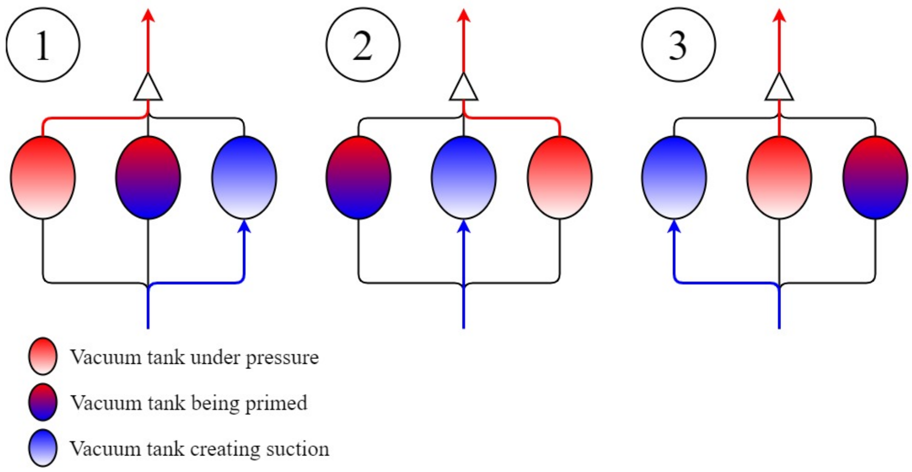


Figure 6.9: Loading system using three vacuum tanks seen from above. Blue arrows indicate suction lines, and red arrows indicate pressure lines.

The configuration shown in Figure 6.9 has the overt disadvantage of taking up space. As SBVs are area-critical, this configuration may be impracticable. Another pump type that could be more suitable is an ejector type pump. Ejector pumps use a partial flow under high pressure to draw a main stream of fish and water from the production cage [49]. The flow from the production cage has a greater volume but lower pressure. Pumping water into a narrow passage creates a vacuum effect that sucks in the water from the production cage. Figure 6.10 illustrates the principle. The fish moves from the production cage, through the ejector pump's narrow passage, and further into the processing plant.

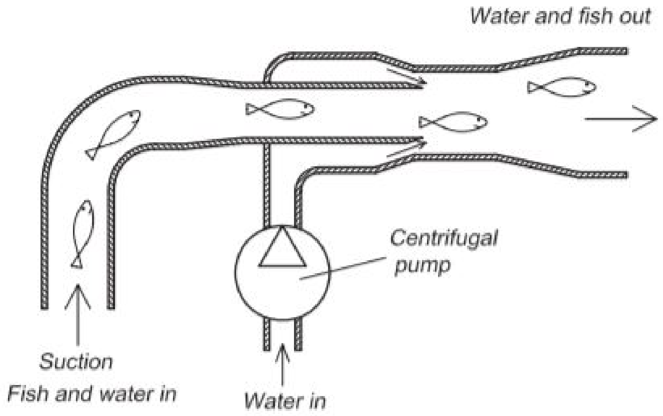


Figure 6.10: The ejector pump principle [49]

This pump has the advantage of continuous flow, the salmon is not exposed to air, and the salmon is not in contact with any part of the pump. However, the principle only works in one direction. Reconfiguration upon unloading could done by connecting the suction side (to the left in Figure 6.10) to the RSW tanks. Moving dead salmon and water containing waste products (fish blood and mucus) through the pump means it has to be cleaned.

A slaughterhouse could rely on the vessel providing the pumping capability to unload salmon its facility. However, most facilities have this capability as fish from waiting-cages must be pumped into the factory. Some reconstruction of a slaughterhouse is necessary to incorporate SBVs. If the slaughterhouse chooses to use SBVs as their primary salmon delivery system, most of this configuration involves removing parts of the processing line (as discussed in Section 3.3.2 and illustrated in Figure 3.10). The slaughterhouse's system for pumping fish from waiting-cages into the facility could potentially be moved closer to the processing line and re-tasked for unloading salmon.

6.3.2 Processing plant

After passing through the pressure side of the loading system and into the processing plant, fish and unwanted elements are separated. A grading table like that in Figure 6.11 can be used, if fish are to be sorted and wholly separated from the seawater from the production cage [175].

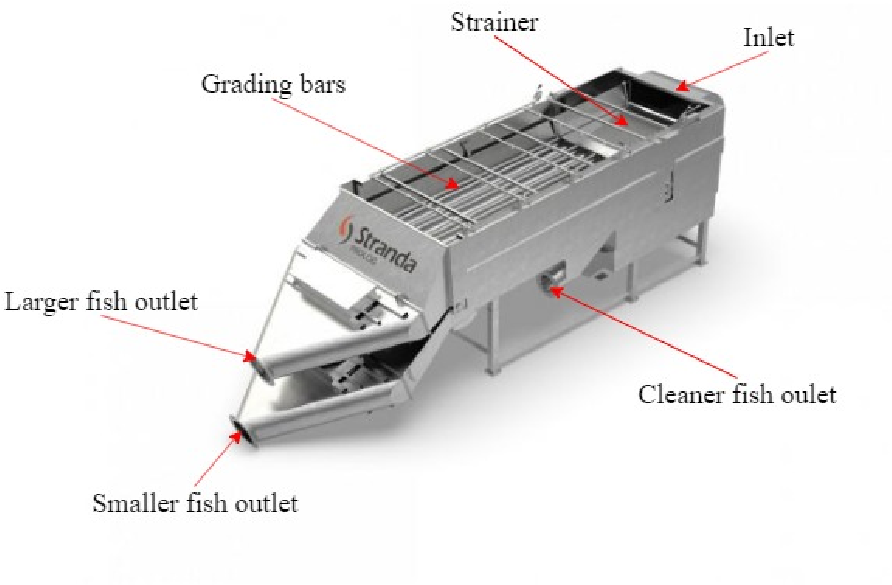


Figure 6.11: Grading table from Stranda Proplog AS [175]. The table in the photo can sort fish from 100 g to 10 kg and has a capacity of 100 tonnes per hour.

A grading table such as this has two main functions: straining out the water and sorting the fish according to size. An inlet situated higher than the fish tube decreases the velocity of the water. The slower speed of fish and water helps to achieve more accurate grading and avoiding damage to the fish. The sorting happens by adjusting the distance between grading bars, stacked at different levels within the table. The larger fish move over the bars, while smaller fish fall through the bars to the next level. Cleanerfish are sorted out at this stage and handled separately from the salmon. According to Moen Marin, their costumers have expressed that sorted fish is somewhat undesirable, as a homogeneous batch of fish will achieve lower packing density in standard fish crates than batches with more mixed sizes.

As discussed in Section 3.3.2, the two main methods for stunning are electrification and percussion. Figure 6.12 shows a typical electric stunning machine. Fish move along a conveyor belt with metal netting, acting as one pole in the electric circuit. Several metal strips hang above the salmon, acting as the second pole in the circuit. The strips are hinged, moving as the salmon moving along the conveyor pushes them. The contact creates an electric short-circuit that stuns the fish.

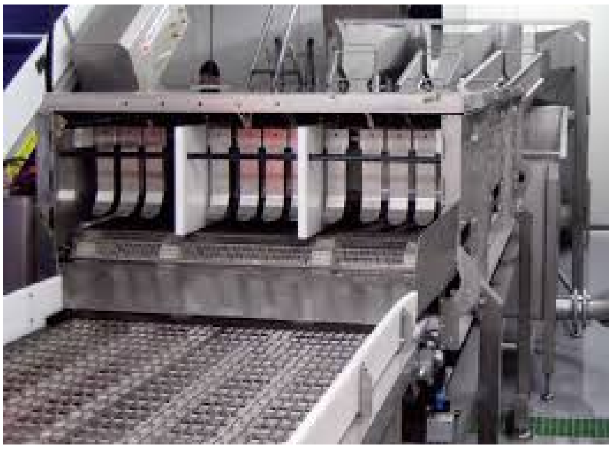
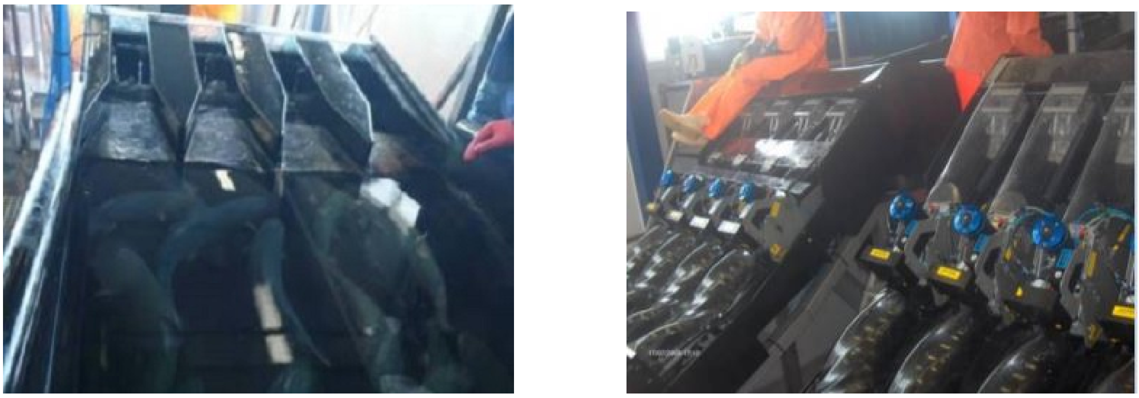


Figure 6.12: Electrical stunning machine from Seaside AS. Image source: Frode Håkon Kjølås.

Figure 6.13 shows a typical percussion machine using a behavioural tub, as described in Section 3.3.2 [176]. The salmon swims towards the machine in the behavioral tub (6.13a) and falls into a slot (6.13b. In the slot, the salmon receives a blow to the head from a metal bolt moving at high speed, causing a concussion that subsequently stuns the fish. Water flowing at high velocity in the behavioral tub can stimulate the salmon's desire to swim towards the slots. Some percussion machines can kill the salmon at the same time, cutting the salmon's main blood vessel in the throat [177]. Percussion machines that kill the salmon after it passes through the percussion stunner have to be equipped with a device that turns the fish, for the salmon receive a cut at in the correct spot.



(a) The inlet side of a percussion machine.

(b) The outlet side of a percussion stunning machine.

Figure 6.13: Percussion stunning machine, showing the inlet (a) and outlet (b) side of the machine [176].

The choice of stunning method depends on operational philosophy, as both methods have their benefits and drawbacks. Electrical stunning machines can cause issues with quality in the form of breaking the backbone of the fish and internal bleeding [177]. This problem is related to the adjustment of the electric current, but the problem has decreased in recent years. The salmon often enter the electrical stunning machine tail first, as fish and water have to be separated before the fish moves along the conveyor. For many systems, this means the fish has to be turned before entering a killing machine. In conversation with Moen Marin killing machines that can create a 3D image of each fish has been developed. 3D imaging allows the machine to identify the orientation of the fish as it moves along the conveyor. Robotic arms that can move independently along a part of the conveyor and across its width uses the image information to cut each salmon in the correct spot. Figure 6.14 shows an automated packaging device that utilizes the same technology. Two robotic arms can be seen in the middle of the figure, along with an image processor to the left.

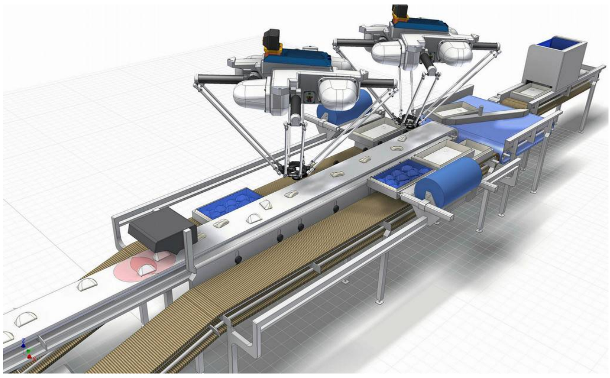


Figure 6.14: Automatic packaging table from Optimar. Image source: Optimar.

Percussion stunning machines with behavioral tubs exploits the natural behavior of salmon. If the fish is hit with enough force from the metal bolt, the fish dies immediately. However, this machine type does have issues with fish of different sizes [177]. The slots can be adjusted according to the expected size, but this does not guarantee that all fish are stunned correctly, thereby not meeting the requirement of stunning the fish before killing it. Cleanerfish and emaciated fish mixed with the harvested fish are particularly vulnerable.

6.3.3 Refrigerated seawater (RSW) system

Refrigerated seawater (RSW) refers to systems where seawater, by some form of mechanical refrigeration, is cooled to just below 0°C [178]. LFCs transport live fish in RSW tanks, for reasons discussed in Chapter 3, while SBVs use RSW tanks for preserving and stabilizing the dead fish. Once the fish is dead, an irreversible process of loss of quality has started. In Section 5.3 pointed out the importance of using chilling as a preservative measure for fish. A schematic representation of an RSW system can be seen in Figure 6.15. The figure is inspired by [179], [180], [181], and [182]. In this set-up, there are three unmixed liquid flows; seawater line cooling the refrigerant in a condenser, the RSW line is cooled by the refrigerant in an evaporator, and a closed circuit containing a refrigerant.

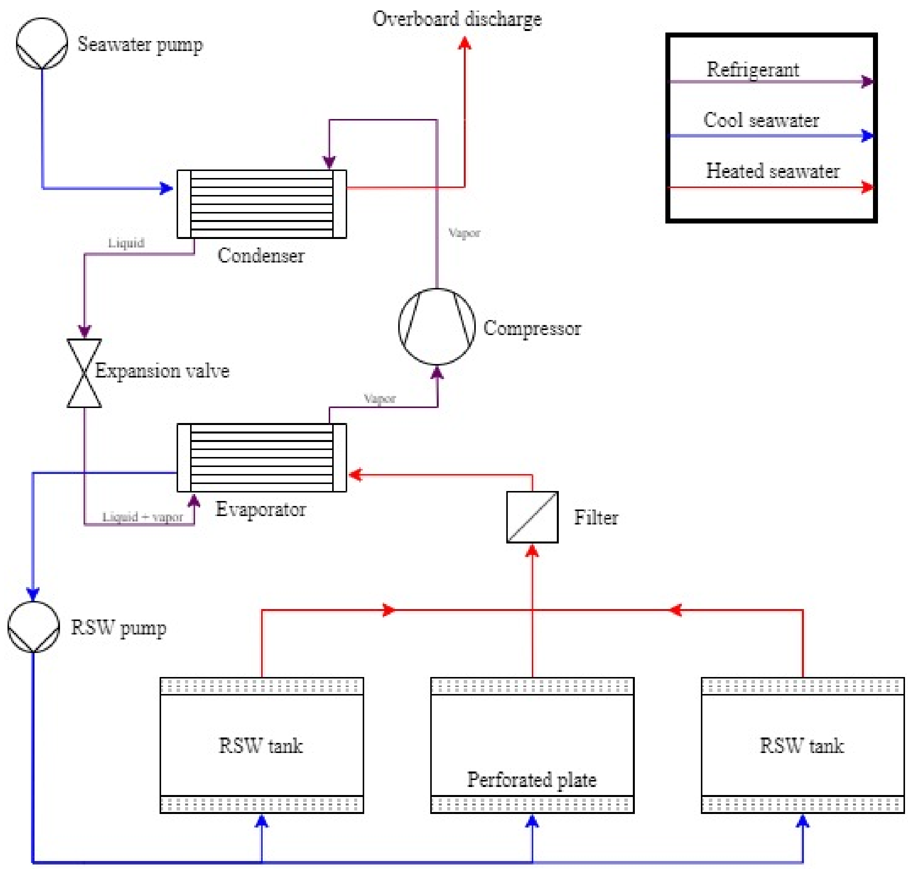


Figure 6.15: Principle of a RSW system with three RSW tanks.

The circuit with a refrigerant follows a typical *Vapor-Compression Refrigeration* (VCR) cycle. This part of the system consists of a compressor, a condenser, an expansion valve, and an evaporator. Water from the pre-filled RSW tanks is pumped through the evaporator, where thermal energy from the seawater evaporates the refrigerant. The low pressure refrigerant vapor from the evaporator goes through the compressor and leaves as high pressure vapor. The heated, compressed refrigerant vapor moves through a condenser. The condenser and evaporators are typically shell-and-tube heat exchangers.

Shell-and-tube heat exchangers are area demanding installations. Pipes and tubes necessary for flow and system function also demand space. The RSW tanks onboard an LFC are specifically designed to transport live fish. The lowered temperature in the tanks is intended to lower the metabolic rate of salmon. A functional requirement for the SBV is to keep the dead salmon temperature below 2°C. Therefore, insulation is more important for the RSW tanks onboard SBVs, because of the higher temperature difference between the water in the tanks and the ambient temperature.

A uniform distribution of fish and water within the tank during transport is essential. If water flow or gravitational forces were to cause fish to congregate into clusters, the cooling effect for the fish within these clusters would be worse, and pressure could impair the quality as the fish will chafe against each other. Directing a gentle flow of water through perforated plates at the bottom of the RSW tanks (as seen in Figure 6.15) avoids fish congregating and causes better heat distribution.

Choosing the number of tanks relies on other factors than that for LFCs. When the vessel "Tauranga" went through reconstruction, the original two tanks were separated into six closed compartments [183]. The reconstruction was to ensure *first-in-firs-out* handling of the processed fish. This method implies the need for a system that can unload each tank separately.

6.3.4 Hygienic systems

All systems that have been in contact with salmon have to be cleaned and disinfected after salmon is delivered. Equipment for cleaning and disinfection has not been evaluated in this thesis, although they are listed as requirements. The wastewater from the RSW tanks has to be properly dispersed. Slaughterhouses have to handle wastewater from their processing lines without the use of SBVs. Therefore it is assumed that the SBV can unload salmon and process water at slaughterhouses. Removing blood from salmon after killing it should be done to obtain higher quality, and to reduce the risk of microbial spoilage. Installing a bleeder tank onboard an SBV, in addition to RSW tanks, is potentially too space demanding. According to Moen Marin, a technology that ensures sufficient bleeding of fish after killing it does already exists. After being killed, the salmon moves through a tube with water that diffuses the blood out of the fish. The wastewater is stored in a separate tank. Filtering out particles and blood from the RSW tank is also a possibility. This method implies upscaling and potentially adding systems to the filter seen in Figure 6.15

7 Evaluation of SBV vessel types

This chapter evaluates the use of the main operational modes of SBVs, illustrated in Figure 6.3. In Section 7.1 the use of medium to large SBVs is evaluated against the requirements found in Chapter 5 and 6. Section 7.2 presents the use of the Emergency type SBV and evaluates its potential in Norway. As discussed in the previous chapters in this thesis, the intended mission of an SBV has greater implications on the design of the vessel than the LFC missions have on LFC design. The reason for this has mainly to do with the choice of cargo capacity and choice of mission-related systems presented in Chapter 6.

7.1 Regular harvest transportation

Regular harvesting is equivalent to the mission type that LFCs do during harvest operations, transporting salmon ready for harvest, in some cases salmon in need of harvest due to disease or parasites, from production sites to slaughterhouses. This section takes a closer look at the claims made of the advantages related to the use of SBVs when compared to LFCs. These claims are most noteworthy made in a Nofima report from 2011 [12]. The claims are related to economy, efficiency, fish welfare, quality, shelf life, disease and contagiousness, logistics, documentation, and food safety. The research also uncovered several drawbacks with SBVs, compared to LFCs, and section contains discussion related to these drawbacks and how they are possible to mitigate in 2020.

7.1.1 Efficiency and economy

A common claim made about SBVs is that they are more efficient at transporting salmon than LFCs. This is because SBVs utilize more of their cargo space (80 % of RSW volume utilized in SBVs versus 8-12 % in LFCs) [12]. The increased efficiency means SBVs are smaller than LFCs, reducing construction costs. However, as illustrated in Figure 6.4, RSW tank volume versus gross tonnage (GT) is at best 1:2 for SBVs. The equivalent relationship for an LFC is 1:1. An LFC with RSW tank volume of 2000 m^3 has an estimated size of 2000 GT. With a relatively high tank stocking density of 150 kg/m^3, the vessel can transport approximately 300 tonnes of live salmon. An SBV with the same cargo capacity needs a minimum RSW tank volume of 375 m^3 (using 80 % stocking density). The size of the SBV would at best be 750 GT. Based on GT alone, an SBV harvest vessel is approximately 60 % smaller than an LFC with comparable transport capacity. Assuming that the costs of fish handling systems onboard the two vessel types are comparable (life-supporting systems onboard the LFC and processing plant onboard the SBV), the difference in size alone constitutes a considerable difference in shipbuilding costs. The reduced size also means lower emissions and fuel consumption per kg transported salmon [12]. Lower fuel costs implies lower VOYEX, and an SBV shipowner should be able to offer lower freight rates to farmers than LFC owners.

Ton miles is a measure of vessel efficiency, defined as tonnage of cargo shipped, multiplied by the average distance over which it is transported [106]. In the case where everything within the utilized cargo space is defined as cargo, including water, the SBVs are up to ten times more efficient than LFCs (80 % of cargo is payload in

SBVs, with as little as 8 % in LFCs). Figure 7.1 shows the results of estimating the RSW tank volume needed using a few different transport modes, based on historic data. The data used as a basis for the figure can be found in Appendix B. The total amount of slaughtered salmon in the period 2009-2019 is represented by a yellow line in the.

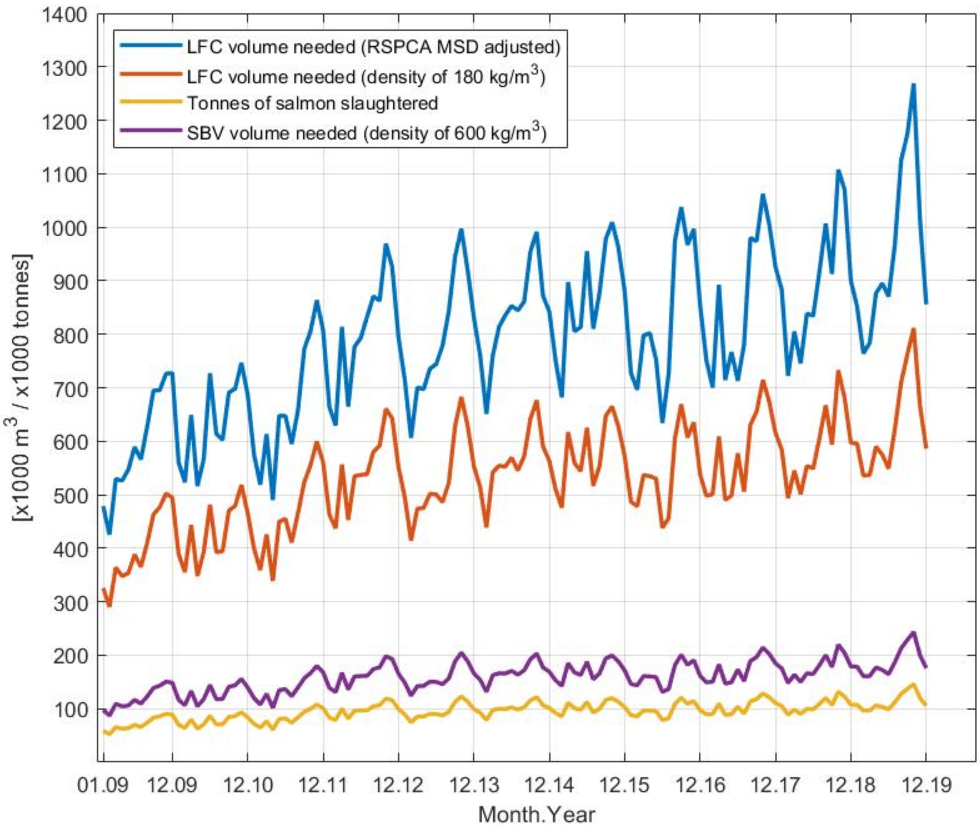


Figure 7.1: Estimated RSW tank volume needed to transport the historic amounts of salmon in Norway in the period January 2009 to December 2019.

As discussed in Section 3.4.1 Norwegian regulation does not specify a required stocking density onboard LFCs. The blue line in Figure 7.1 is the time series of needed LFC cargo volume adjusted for the maximum allowed RSPCA standard stocking density (see Table 3.1). Stocking densities of more than 125 kg/m^3 are not uncommon in Norway. According to some LFC owners, a stocking density of 180 kg/m, or even higher, is considered acceptable (depending on the systems used) [184]. Therefore, a conservative stocking density of 180 kg/m^3 stocking density is used to estimate the necessary LFC cargo volume, represented with an orange line in Figure 7.1. The month in the time series that had the highest slaughter volume in tonnes was October 2019 (more than 140 000 tonnes slaughtered). Using RSPCA adjusted cargo volume, an estimated 1 269 000 m^3 of LFC cargo volume would be required (396 round trips using only 3200 m^3 LFCs). Without the adjustment, using a stocking density of 180 kg/m^3, 811 000 m^3 of cargo volume would be required (254 round trips using a 3200 m^3 LFC).

The assumed maximum stocking density in RSW tanks is claimed to be 80 % (or approximately 800 kg/m^3) [12]. In Figure 7.1 a stocking density of 600 kg/m^3 is set for SBVs, as a conservative estimate. There are two reasons for this: 1) a high stocking density could, as discussed in Section 6.3.3, cause fish congregating and subsequently, a poor chilling effect and chafing between fish; 2) The shift-capacities of slaughterhouses vary. Reason 2) can be illustrated with an example: A large stun and bleed vessel, able to carry 200 tonnes of salmon with an RSW tank stocking density of 800 kg/m^3 has an RSW tank volume of 250m^3. The vessel is in service of a farmer that owns a slaughterhouse with a shift-capacity of 200 tonnes of salmon. Therefore, the interaction between SBV and slaughterhouse is optimized. Due to lack of transport capacity at another slaughterhouse owned by the farmer, the farmer temporally tasks the SBV with transporting salmon for this slaughterhouse. The slaughterhouse in question has a lower shift-capacity of 150 tonnes of salmon. When servicing the slaughterhouse with the 150-tonne shift capacity, the SBV can only utilize 60 % of its RSW tank volume. Therefore, the RSW tank volume needed to transport the historical harvest volume in Figure 7.1 has been estimated using a stocking density of 600 kg/m^3.

Estimating the exact number of SBV round trips necessary to transport the historic production volume depends on the shift-capacity of the slaughterhouses, how many SBVs exist, and each SBVs cargo capacity (as illustrated in the example in the paragraph above). If SBVs were to replace LFCs as a means for harvest transport wholly, live transport for smolt and delousing operations carried out by LFCs would still be necessary. The optimization of the Norwegian salmon fleet composition is out of the scope of this thesis, but the subject is worth further investigation.

With the use of SBVs, the owner of a slaughterhouse can eliminate costs related to investing in and maintaining waiting-cages [12]. In some cases, the on-shore processing facilities may favor waiting-cages to direct-unloading due to local conditions. In a request for establishing waiting-cages outside their facility in Hammerfest, Cermaq AS used unstable and rough weather conditions at production sites as justification [185]. The company requested waiting-cages to be able to ensure a more steady flow of salmon to the facility. LFCs were, in some cases, unable to load salmon at the weathered sea production sites. This example illustrates the logistical value of waiting-cages and why slaughterhouses in certain areas may be reluctant to rid themselves of the cages. Their smaller size also means SBVs are more affected by environmental loads such as waves and current. However, large LFCs sometimes have severe issues with maneuvering around production cages at production sites [172]. The smaller sizes of SBVs gives them an advantage in this operational context. However, SBVs have to be ready to unload the salmon at the slaughterhouse when the work shift starts, typically in the morning. Depending on distance from production cage to slaughterhouse, the on-site slaughtering operation has to start the evening or night before. Operating in darkness is not uncommon in Norwegian aquaculture, but does imply increased operational risks.

During live salmon transports some fish will die in the tank and have to be discarded when arriving at the processing facility (between 0.5 and 1 %) [12]. Depending on the salmons condition, the time they spend in waiting-cages, and the handling during crowding at the slaughterhouse, more salmon will die. Using a conservative estimate of 0.5 % of salmon transported from a production cages dies due to reasons mentioned above, an estimated 2 tonnes of salmon from a transport batch of 400 tonnes is discarded. With an average superior price value of 50 NOK/kg this implies a loss of 100 000 NOK. No salmon are lost due to death before being processed when using an SBV (however, a small amount of weak fish could die before reaching the processing plant). A standard price deduction for salmon of ordinary quality is 1-2 NOK/kg, and 5-15 NOK/kg for production quality grade [140]. The loss of 100 000 NOK can be equated to having 12.5 % of the 400 tonne batch of salmon downgraded to ordinary quality (2 NOK deduction from 50 NOK/kg) or 1.7 % downgraded to production quality. The Nofima study from 2011 reported higher levels of downgraded fish using "Tauranga" (approximately 4 %) but did not specify to which quality grade.

7.1.2 Fish welfare

The use of an SBV only requires one crowding and pumping operation of live fish [12]. The use of an LFC requires at minimum one crowding (at production site) and two pumping operations (loading at the production site and direct-unloading at the slaughterhouse). A slaughterhouse that uses waiting cages has do go through an additional combined crowding and pumping operation. As discussed several times in this thesis, these operations are associated with more inadequate fish welfare and can cause shorter pre-rigor times.

Many of the requirements for the SBVs loading system and processing plant, presented in Section 5.6 and also those in 6.2, originate from regulation requirements for on-shore slaughterhouses. The systems onboard an SBV have to be operated by sufficiently trained personnel [12]. Also, depending on the efficiency of the processing plant, the crowding of salmon at the production site lasts longer compared to using LFCs. In 2011, "Tauranga" had a loading efficiency of 50 to 60 tonnes per hour, while large LFCs at the time had a 200 tonne/hour loading rate. The number of salmon loaded per hour is a more suitable metric describing SBV loading capacity, as each fish has to be individually handled in the processing plant. Aqua Merdø has a loading capacity of 20 000 fish per hour [186]. The vessel claims to have a cargo capacity of 400 tonnes (utilizing 80 %) of RSW tank volume. Loading 400 tonnes of salmon, with individual fish weighing 5.0 kg, at a rate of 20 0000 fish per hour would take four hours. An equal amount of salmon weighing 4.0 kg would take five hours to load. The longer loading times for SBVs illustrate the importance of having onboard systems that allow for low stress-inducing crowding operations (e.g., sufficient crane capability and oxygen regulation). Longer loading times also mean shortening of pre-rigor times, possibly affecting quality.

7.1.3 Quality of the product

Pre-rigor is essential for modern salmon processing. Fish enters rigor in a gradual state, and different parts the salmon can have varying degrees of rigor [12]. Electrical stunning is associated with shorter pre-rigor times [47]. Exhausted fish that is electrically stunned can enter partial rigor after only two hours. Percussion machines are associated with longer pre-rigor times (up to 40 hours). Transport missions involving long distances and large amounts of salmon (longer loading times) would favor the use of percussion-stunning machines. However, as discussed in Section 6.3.2 percussion machines are more sensitive to the size of salmon, resulting in conscious fish being killed or cut incorrectly. The percussion machines also depend on salmon being able to swim in a behavioral tub. Salmon weakened from disease or treatment operations may not be able to swim as anticipated in the behavioral tub [12].

7.1.4 Disease and parasites

Live transportation of salmon imposes a significant risk of spreading disease along its transport route [117]. Although many have disputed the notion of LFC being responsible for the spread of PD, a recent study indicated that there are high levels of risk associated with spreading PD when using LFCs for live fish transport [187]. Section 3.2 discussed the LFCs' role in the spread of ISA in Scottish waters in the late 1990s. Slaughterhouses using SBVs can discontinue the use of waiting-cages, or by limiting their frequency of use, limit the negative impact the cages can have on the surrounding environment. If the regulation concerning salmon louse is updated as proposed by the NFSA (see Section 4.3.3), slaughterhouses that can receive salmon from SBVs have a logistical advantage over LFCs.

SBVs are especially suited for transporting sick or treatment-weakened salmon [12]. Many areas in the west- and southern parts of Norway are affected by PD and CMS. Salmon infected by PD are weak, and closed-well systems have to be used in PD-zones. Also, unloading salmon with PD into waiting-cages is illegal, requiring systems with direct-loading capabilities, such as SBVs. LFCs have direct-unloading capabilities, but loading fish into a slaughterhouse could be time-consuming, increasing the risk of salmon dying in the LFCs RSW tanks. High stocking densities over long periods is also a welfare issue. The LFCs could decrease their transport stocking density, but this makes them even more inefficient as a means of transport. It is difficult to identify salmon infected with CMS, and the disease is often most severe towards the end of the salmon's life. The stress involved with live transporting could result in high levels of salmon mortality before reaching a slaughterhouse. Farmers in areas with CMS would decrease the risk of losing fish during harvest transport if they utilize SBVs.

7.2 Emergency stun-and-bleed vessel

During all operations involving the handling of farmed salmon, there is a risk of individuals dying due to stress or complications from injuries. With the increased frequency of mechanical and thermal delousing operations, the number of individual salmon deaths has increased [10]. In the modern aquaculture industry, the most common practice for handling fish that is close to death is to perform emergency slaughter on affected fish. Due to food and safety regulations, this fish will end up as silage, not meant for use in products suitable for human consumption [188]. Turning salmon into silage marks a severe reduction in the value of an otherwise highly valuable raw material, both in economic terms and as a nutritional resource. Using stun-and-bleed technology on a smaller vessel could prevent at least part of the over 40 million individual salmon from becoming silage, and used more sustainably.

It can be difficult to evaluate the condition of the fish. Is it dead, and thereby not fit for human consumption, or are the vital signs so weak that it is hard to tell the difference? Treatment operations like that of mechanical and thermal delousing have different effects on depending on several factors (e.g., method used, condition and size of the fish, seawater temperatures and more) [10]. Some fish will be dead before going through any processing and must therefore, due to regulations, be separated from fish meant for human consumption. Being able to sort dead from live fish must therefore be a feature of any SBV, but particularly for an emergency SBV as these by definition process weak salmon. A method, where the response of the fish from electrical stimuli during the stunning phase, has been developed and a vessel with this patented technology should according to schedule start operations in Norway by February 2020 [189], [190].

7.2.1 Potential export value of lost salmon

The Norwegian salmon farming industry lost more than 53 million individual salmon, during the sea production phase, in 2018 [71]. The company PricewaterhouseCooper (PwC) estimated that the value lost in 2018 amounted to 16 billion NOK [142]. The assumption was that each lost salmon, on average, weighed 5 kgs and was worth, on average, 50 NOK/kg. A farmer utilizing emergency SBVs can potentially reduce his economic loss due to dead salmon. However, purchasing a vessel or service from an emergency SBV also has an expense. Sixteen billion NOK is a considerable amount on which to base an investment on. However, an equally simplistic calculation illuminates an issue. There were approximately 1000 production sites in operation at any given time in 2018 in Norway [191]. If an equal amount of salmon dies in each cage, equally distributed across every hour of the year, the 16 billion per year loss constitutes roughly 1800 NOK/hour per site.

A more accurate estimation of potential income, based on the real value at the salmons time of death, is possible. The Norwegian Directorate of Fisheries publishes production loss data, reported by farmers every month [71]. Combining the monthly production loss data with average monthly export prices from the NASDAQ Salmon Index [126] provides a more accurate and conservative estimation of the potential value of lost salmon (Figure 7.2). The underlying calculation for the figure accounts for the estimated weight of the salmon and the historic average export price of superior quality salmon of that weight, in the month the salmon died. The blue bars in the figure indicate values in 2019 NOK, adjusted using the Norwegian Consumer price index [192]. See Appendix D for more details on the figure's underlying calculation.

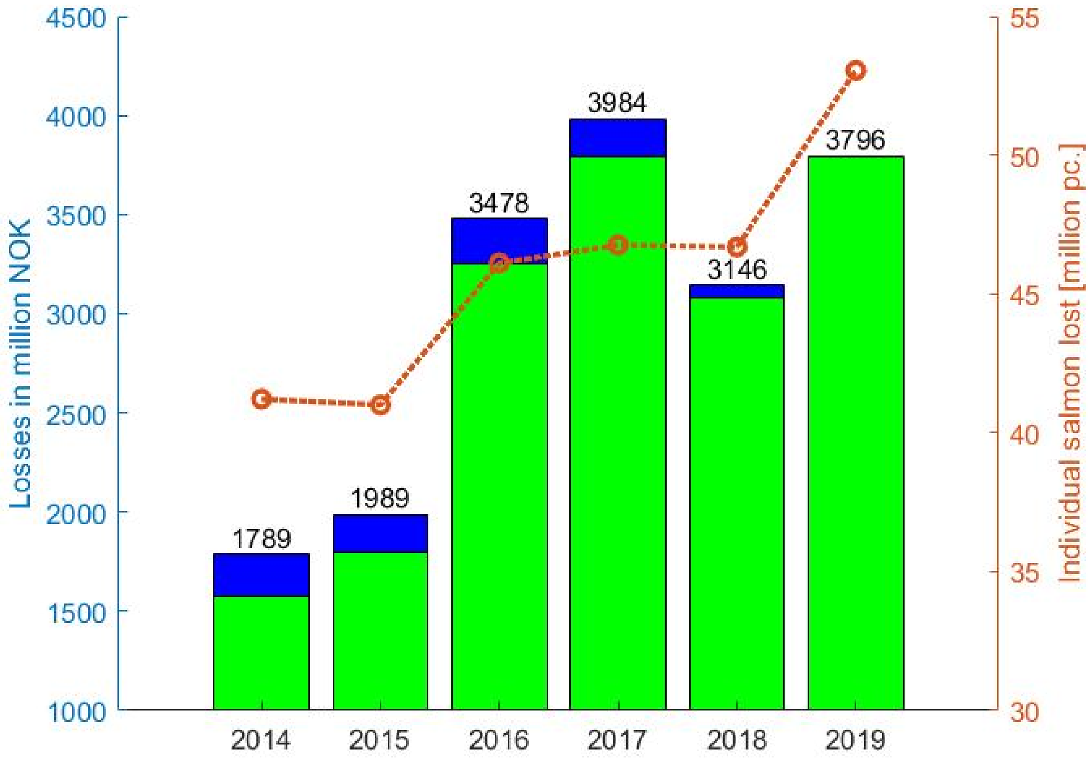


Figure 7.2: Estimated export value of lost salmon, due to death in the sea phase 2014-2019. Based on data from the Norwegian Directorate of Fisheries and the NASDAQ Salmon Index. Blue bars indicate 2019 values, using Norwegian Consumer price index.

The estimation shown in Figure 7.2 is arguably not conservative enough, as the underlying calculation is based on export prices of superior quality salmon. The calculation also assumes that the salmon lost weighed the same as the monthly average weight of salmon in the sea on a county basis. As discussed in Chapter 4, salmon can die from disease and parasites. A large quantity of the salmon that dies before processing is not suitable for human consumption, e.g., emaciated fish or of lower quality. The weight of these fish are considerably lower than that the other salmon in the same cage. According to Norwegian regulation on the quality of fish and fishery products [93], lower quality salmon can be used for human consumption if processed correctly (see Section 5.3). Still, the question of profitability remains. Processing of fresh rest raw material from salmon, meant for human consumption, will obtain a lower price than fresh HOG or fillet exports. Estimating the available raw material from the biomass loss is essential.

7.2.2 Identifying areas of interest

Figure 7.3 shows the estimated national yearly biomass losses of different salmon cohorts (see Appendix E for more details). During the period displayed in the figure, the total biomass loss had more than doubled from 40 000 tonnes in 2009 to more than 100 000 tonnes in 2019. The significant increase was largely attributed to the death of salmon released the previous calendar year (1 yr cohort in the figure). The biomass loss due to 1 yr cohort salmon deaths decreased in 2018 but spiked in 2019, the same pattern as seen in Figure 7.2. Salmon released more than one calendar year ago is seen as >1 yr cohort. If biomass numbers are from May 2019, all salmons released in 2018 are defined as salmons from a 1 yr cohort, all salmons released in 2017 are defined as >1 yr cohort, and salmons released in 2019 are defined as salmons from a 0 yr cohort.

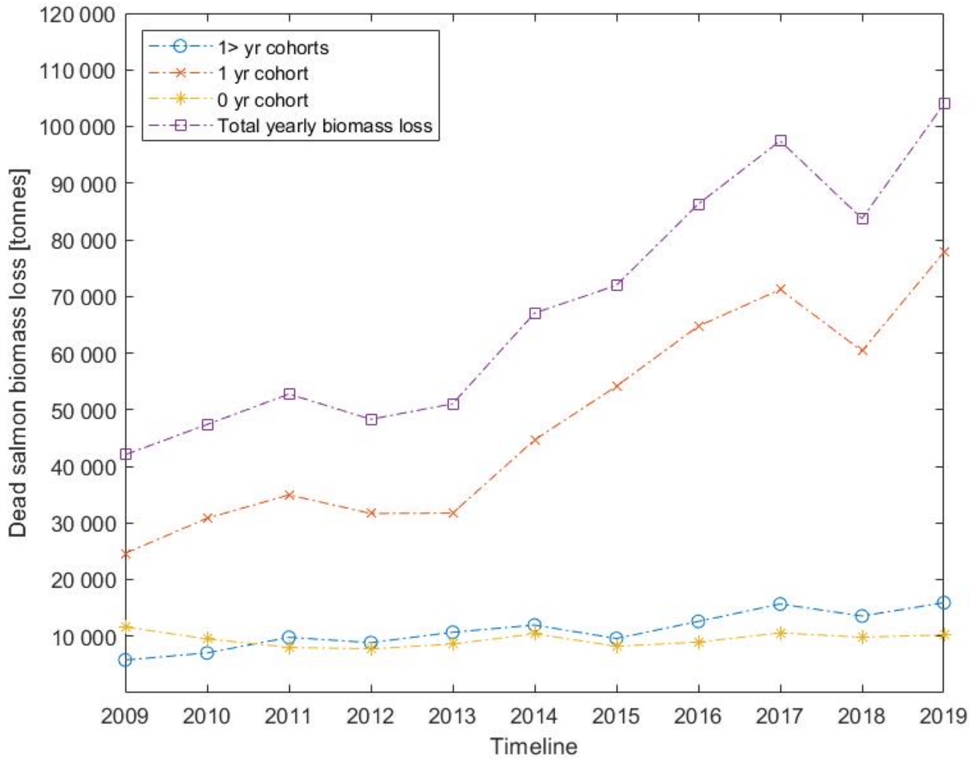


Figure 7.3: Estimated yearly national biomass loss, in tonnes of live weight equivalent (LWE), of different salmon cohorts due to death in the sea (2009-2019).

In May 2019, farmers in Troms and Nordland experienced a bloom of toxic algae. According to NDF figures [71], Troms lost an estimated 6962 tonnes of biomass, and Nordland lost 8046 tonnes of biomass, in May 2019. The 2018 corresponding figures were 482 and 967 tonnes, respectively. If the algae bloom had not occurred, the total national losses would have amounted to an estimated 90 000 tonnes (somewhere between 2017 and 2018 national losses in Figure 7.3). Using the same method for calculating the losses in Figure 7.2, the algae bloom killed salmon worth more than 480 million NOK. Most of the biomass lost in the algae bloom was 1 yr cohort salmon (approximately 96 % in Troms and 90 % in Nordland). In any given year from 2009 to 2019, the national average weight of 1 yr cohort salmon grew from approximately 1 kg to approximately 4 kg, from January to December (see Figure 7.4). The drop in average weight of 1 yr cohort salmon in Figure 7.4 indicates the start of a new year (remaining 1 yr salmon cohort salmon moves into >1 yr cohort category). As salmon from the 1 yr cohorts are on average larger in the fall (reaching an average weight of approximately 4 kg in November), this is the time of the year when losses of 1 yr cohort can have the largest impact on profits. As mentioned in Section 4.3.3, the most significant amount of adult female lice occurs during the fall, making it the season with the highest amount of delousing operations.

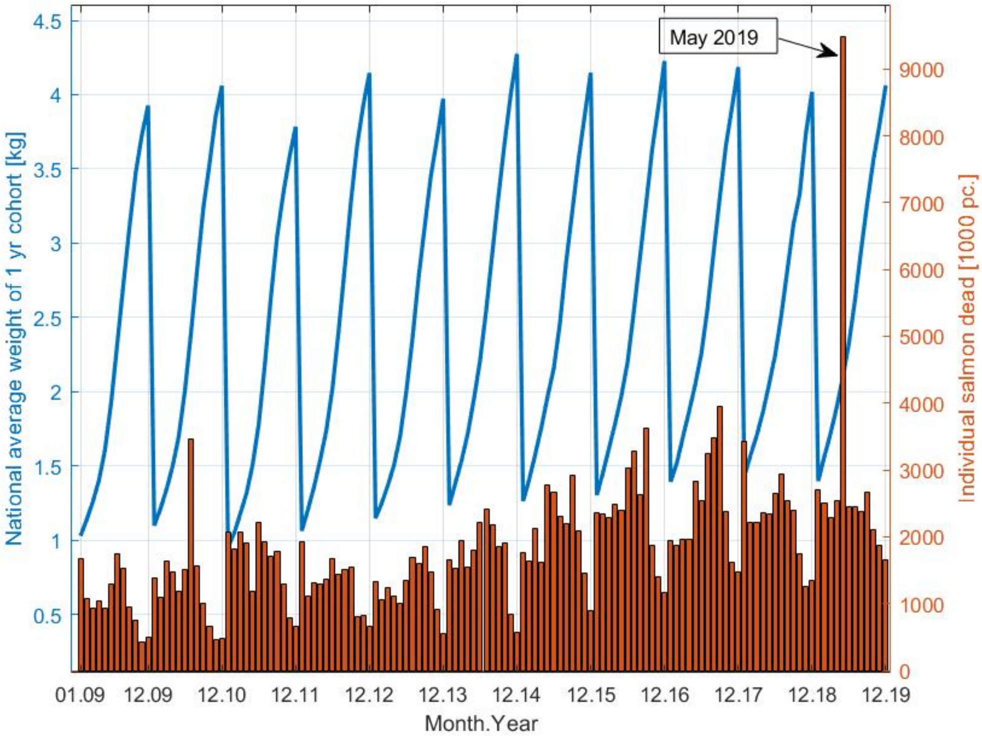


Figure 7.4: Estimated yearly national weight average of 1 yr cohort salmon versus national monthly individual 1 yr cohort salmon deaths (2009-2019).

Identifying areas where the biomass loss is the most concentrated in time and area (i.e., highest biomass loss per production site) will distinguish areas for economically efficient emergency slaughter efforts. Based on the information presented on CMS, PD, and salmon louse in Chapter 4 indicate that the largest concentrations of salmon deaths would be south of Nordland county. Figures 7.5, 7.6 and 7.7 show the estimated monthly average biomass losses per cage and locality (production site) of eight salmon farming counties (pre-2020 counties are used as the data from NDF uses historic naming for data sets from before 2019). Compared to the other counties and regions, Finnmark appears to lose a relatively small amount of biomass per locality each month. The regions Troms and Nordland also experience comparatively low monthly biomass losses. The most visible exception being the month of May in 2019. Nordland lost more than 65 tonnes and Troms more than 113 tonnes per locality on average.

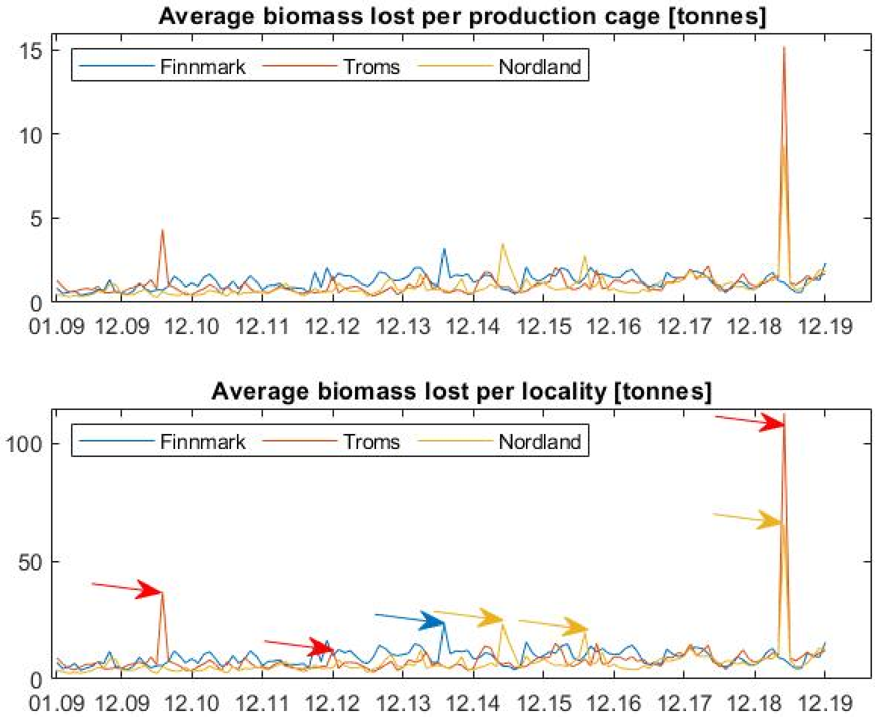


Figure 7.5: Estimated monthly average biomass losses per cage and per locality in Northern Norway counties (Finnmark, Troms and Nordland), in 2009-2019. Arrows mark local outliers that are more than 3 times the standard deviation of the moving mean within a 24 month time window.

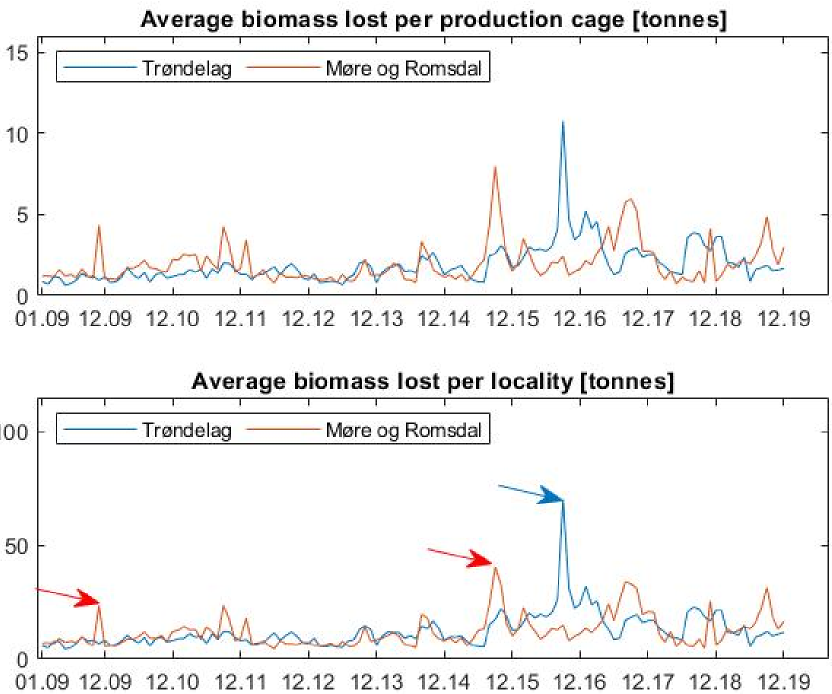


Figure 7.6: Estimated monthly average biomass losses per cage and per locality in Central Norway counties (Trøndelag and Møre & Romsdal), in 2009-2019. Arrows mark local outliers that are more than 3 times the standard deviation of the moving mean within a 24 month time window.

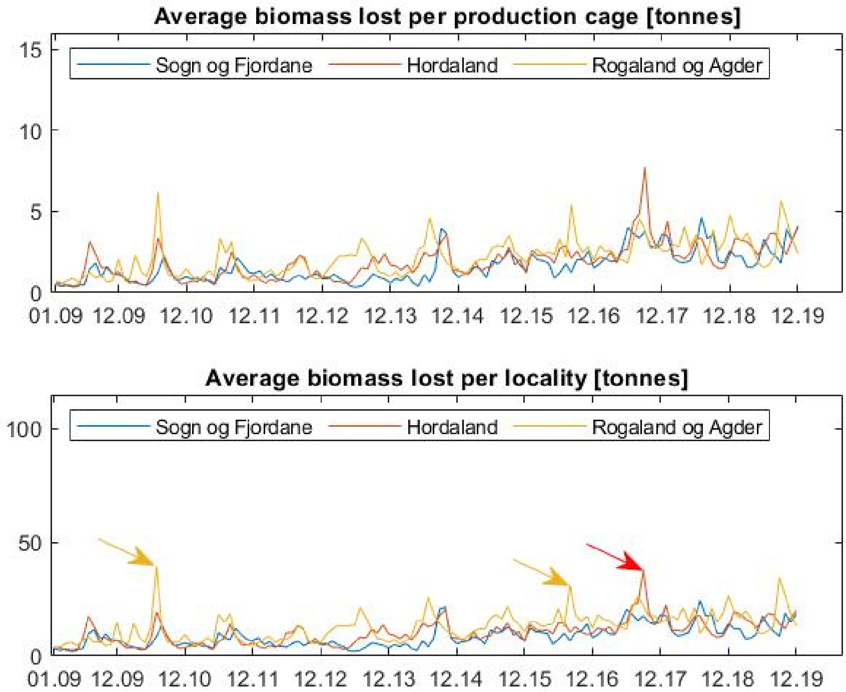
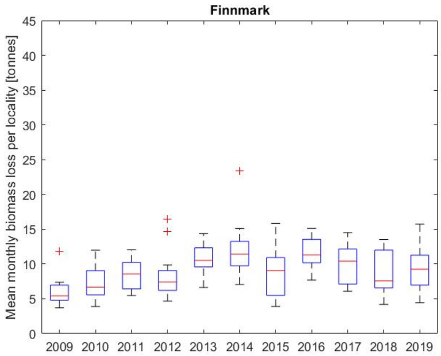


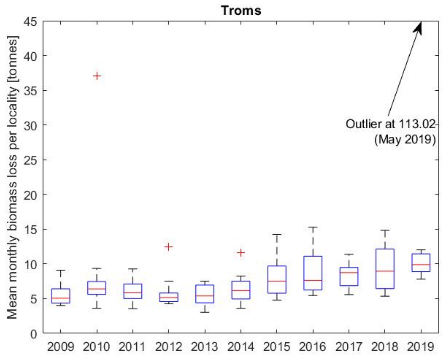
Figure 7.7: Estimated monthly average biomass losses per cage and per locality in Southern Norway (Sogn & Fjordane, Hordaland and Rogaland & Agder), in 2009-2019. Arrows mark local outliers that are more than 3 times the standard deviation of the moving mean within a 24 month time window.

The central region (Trøndelag and Møre & Romsdal) have seen several spikes of salmon death between 2009 and 2019. Most noteworthy in Trøndelag in September 2016. This was the first year the use of mechanical and thermal delousing became mainstream, and the effect on fish welfare and post-treatment mortality rates were relatively unknown [10]. Coincidentally, 2016 was a year when production cites around Frøya island experienced massive problems related to salmon louse infestation, and farmers were unable to keep louse levels down below the legal limit [193]. Farmers had to slaughter large quantities of salmon before reaching a desired size, and many reported not being able to slaughter fish before the louse induced severe injuries upon the fish. The death of weak and injured salmon likely caused the high mortality rate, seen in Figure 7.6.

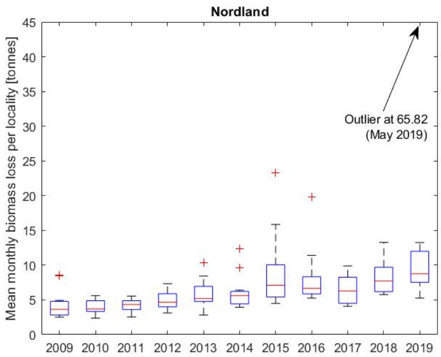
Based on the figures above, it does appear to be the case that it is the southern counties that have the largest concentrations of salmon deaths. Although events such as that in Nordland and Troms in May 2019 and Trøndelag 2016 caused enormous losses for farmers, the southern counties seem to have a more "stable" amount of salmon dying in relatively high concentrations. In Figure 7.8 box plots of monthly loss of biomass due to death in the sea phase, for all counties can be seen. The boxplots have been produced using the boxplot function in MATLAB. For more detailed figures, see Appendix E. No statistical analysis of the data has been done. The box plots have mainly been used to remove outliers (such as May 2019 in Nordland) from the data, showing a clearer development in the counties.



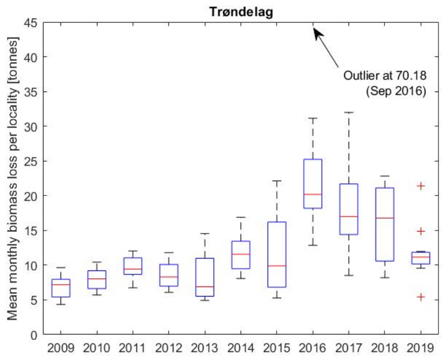
(a) Finnmark



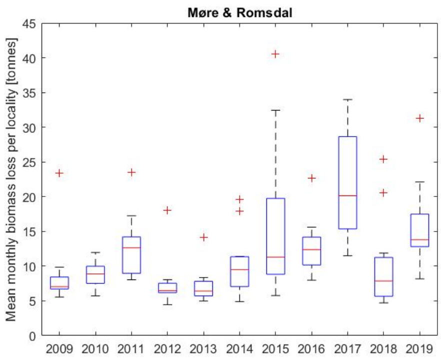
(b) Troms



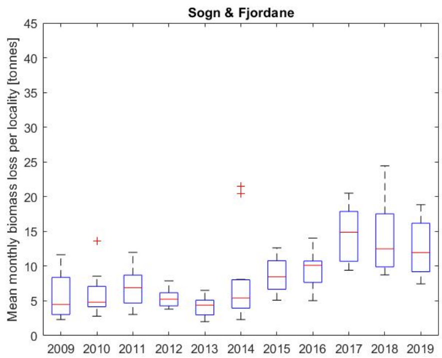
(c) Nordland



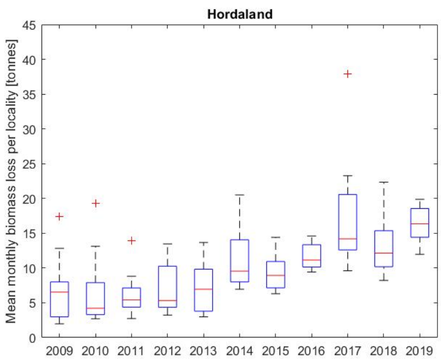
(d) Trøndelag



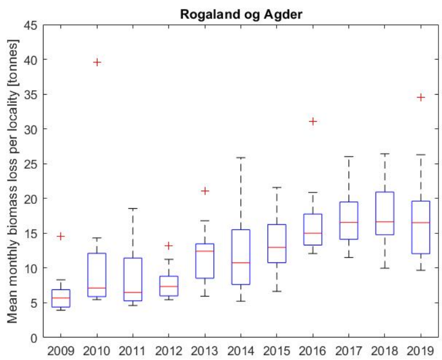
(e) Møre & Romsdal



(f) Sogn & Fjordane



(g) Hordaland



(h) Rogaland & Agder

Figure 7.8: Box plots of monthly biomass loss per locality in eight counties/regions, 2009-2019

In Trøndelag (Figure 7.8d), an increase in median deaths seems to have occurred in 2016, which does coincide with the use of new delousing methods, causing an increase in salmon mortality [10]. The county appears to show a decrease from 2016 to 2019, which may support the notion that the new delousing methods are becoming more optimized. Mortality rates are still higher than that of counties north of Trøndelag. Both Finnmark and Troms appear to have low mortality rates compared to the rest of the country, while Nordland shows a slight increase in median values from 2009 to 2019. Møre & Romsdal has a sporadic distribution of salmon deaths, compared to the other counties. The cause of the distribution seen in Figure 7.8e is uncertain. Sogn & Fjordane shows a similar trend as Trøndelag: increase of median salmon death values from 2015 to 2017, with numbers decreasing in both 2018 and 2019. Hordaland and Rogaland & Agder are the counties with the highest concentration of salmon death in the sea pr month, i.e., average dead salmon biomass per locality. The data also fits with the assumption made at the beginning of this section, based on information presented in Chapter 4.

By law, farmers have to remove dead salmon daily from production cages [80]. The farmers have to grind and store the salmon as silage, with pH values below 4. The silage is typically stored at the production sites in tanks [125]. A handbook from 1993 estimates that 2.0 to 2.5 percent formic acid, of the dead biomass of whole fish, is necessary to obtain a satisfactory pH level [194]. Lactic acid has a density of 1.22 kg/m^3. The price of acid varies according to available global supply (Norway imports all lactic acid) [195]. Assuming a price for acid of 10 NOK/liter and a necessary acid to biomass percent of 2.0, acid costs are roughly 164 NOK per tonne dead fish. Farmers pay approximately 2 500 NOK to silage transporters per tonne (2011 figures) [125]. These costs alone amount to 53 600 NOK for 20 tonnes of dead salmon biomass. In 2019 both Hordaland and Rogaland & Agder had a median loss of approximately 16.5 tonnes of dead salmon per month, per locality. In 2019 Rogaland & Agder had a [Q1,Q3] interval of [12.1,19.6], and Hordaland had a [Q1,Q3] interval of [14.4,19.7] tonnes (50 % of average monthly deaths per locality were between these values).

8 Discussion

This thesis has presented an overview of the overall situation for salmon transport as of 2020. The development of the Norwegian salmon farming industry has been used to put the development of salmon transport into context, thereby mapping essential aspects of the value chain in Norwegian aquaculture, most notably for salmon transportation. Two systems for transporting salmon, the LFC, and the SBV, have been compared against each in the categories efficiency, fish welfare, logistics, quality of salmon, and economy.

Ship design theory focused on its initial stages has been presented and used to generate a requirements list for an SBV. The list is by no means complete and only marks the beginning of the work necessary to initiate a design project. However, along with the information presented and discussed in this thesis, the list forms a basis for further refinement of requirements and design choices. Many important aspects of ship design that will impact the requirements presented have been omitted from this thesis, such as propulsion machinery, hull shape, and more. At the onset of a design project, these systems will have to be taken into account due to the interdependent nature of a ship's systems. Sustainability aspects such as emissions (related to the environment) and job security for local communities (removing waiting-cages could potentially reduce the need for manpower at a slaughterhouse) are also omitted from the requirements list. However, discussions related to the economy in this thesis indicate that the SBV is potentially more suitable for future harvest salmon transport than the LFC. LFCs are still necessary since this is the only system capable of transporting large amounts of smolt, and they are important in combating the salmon louse.

Technology improvements related to SBVs onboard systems, such as gentle pumping technology, more optimized stunning machines, and automated killing machines, indicate that further improvements of the concept are possible. Due to the strict nature of some requirements related to fish welfare, the development of new systems could be relatively slow. Events such as the algae bloom in northern Norway impose severe financial losses on farmers. SBVs could be more suited for processing fish weakened from sudden impacts, such as algae blooms or extreme weather. However, this has not received much focus in this paper, since basing a concept on few and relatively rare events would involve high risk. Possible future regulation concerning the salmon louse with a change in how average adult female lice are counted would give SBVs a logistical advantage over LFCs. However, many farmers will still perceive the waiting-cages as and advantage, especially in areas where daily delivery to slaughterhouses is uncertain. The structuring of slaughterhouses continues, and they are still increasing their production capacity. However, the move towards larger slaughterhouses has slowed down. An SBV will have to operate for many years, and it is important that large and medium SBVs can deliver required amounts of salmon to slaughtering facilities (meeting the daily shift capacity). If slaughterhouses are expected to have approximately the same production volume as per 2020, future uncertainty related to the usability of SBVs would be less significant.

Concerning diseases, SBVs are favorable to LFCs, as mortality rates of salmon could increase during live transportation. Only PD and CMS have been discussed in this thesis, thereby focusing on the southern parts of Norway. Many other infectious diseases cause welfare issues in Norwegian salmon farming. The use of SBVs for transporting these could be more beneficial than using LFCs. Using percussion stunning seems to be the best method for obtaining long pre-rigor times. However, percussion is less effective when handling weak salmon, as the use of behavioral tubs implies that the fish has to be able to swim towards the stunning slots. For Emergency type SBVs electric stunning machines are perceived to be a better choice. An analysis of biomass statistics from the NDF was done to identify areas that would have the most benefit of using Emergency SBVs. Hordaland and Rogaland & Agder were found to be the counties with the highest concentration of salmon mortality at sea. An economic analysis of the viability of an emergency SBV was not performed in this thesis. However, the alternative cost of losing salmon at sea along with maintaining silage systems and paying silage vessels indicate that these types of SBVs have potential. Processing either weak salmon before a treatment operation, or after the operation is more financially sound than allowing the salmon to die. Processing some of the 40 million or more salmon that die each year for human consumption is more sustainable and arguably better for the industry's image.

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List of Appendecies

Appendix A: Slaughterhouse figures in 2018

Table A.1: Reported figures for Norwegian slaughterhouses in 2018.

Business/ slaughterhouse	Tonnes slaughtered in 2018	Shift capacity (tonnes)	No. of shifts
Salmar ASA - InnovaMar	142000	320	444
Nova Sea AS	43841	305	144
Lerøy Midt AS	66500	300	222
MOWI ASA - Eggesbønes	62000	275	225
Bremnes Seashore AS	42300	250	169
MOWI ASA - Herøy	53000	210	252
Nordlaks AS - N-169	70000	200	350
Cermaq Norway AS - Steigen	10000	200	50
Lerøy Sjøtroll Havbruk AS	58800	200	294
MOWI ASA - Ulvan	77000	190	405
Cermaq Norway AS - Hammerfest	31800	170	187
Lerøy Aurora AS	36800	170	216
Salmosea AS	31500	160	197
Austevoll Laksepakkeri AS	33000	160	206
Martin E. Birknes Eftf. AS	24500	150	163
MOFI AS - Ryfisk	70000	150	467
SinkabergHansen AS	45980	125	368
Viking Fjord AS	25000	120	208
Grieg Seafood AS - Finnmark	26200	110	238
Kirkenes Processing AS	7500	100	75
Hofseth Aqua AS	8800	100	88
Slakteriet AS - Florø	18335	100	183
Vikenco AS	16500	95	174
Wilsgård Fiskeoppdrett AS	18500	90	206
Viking Innovation AS - Alsvåg	10000	90	111
Sekkingstad AS	28000	90	311
Grieg Seafood AS - Rogaland	22000	90	244
Sotra Fiskeindustri AS	14571	85	171
Hardanger Fiskeforedling AS	15000	83	181
Arnøy Laks AS	23717	80	296
Salten N950 AS	27000	80	338
Slakteriet AS - Brekke	8746	80	109
Espevær Laks AS	12850	80	161
MOWI ASA - Jøkelfjord	9500	75	127
Ellingsen Seafood AS	12065	65	186
E. Kristoffersen & Sønner AS	6500	60	108
Breivoll Marine Produkter AS	9000	60	150
Astafjord Slakteri AS	14200	60	237
Kråkøy Slakteri AS	19558	60	326
Pure Norwegian Seafood AS	5500	60	92
Western Seaproducts AS	3500	55	64
Salaks AS	8597	45	191
Flakstadvåg Laks AS	6950	40	174

Appendix B: Regular harvest volume calculation

Data from Excel files available from the Norwegian Directorate of Fisheries (NDF) formed the basis for calculating necessary transport volume [15]. An extract of the Excel data table can be seen in Figure **D.1**. Outtake numbers are reported every month and grouped by the nine counties or areas producing salmon (Finnmark, Troms, Nordland, Nord-Trøndelag, Sør-Trøndelag, Møre og Romsdal, Sogn of Fjordane, Hordaland, Rogaland og Agder). Columns with outtake figures differentiate the number of individual fish (marked in red) and amount (marked in yellow). Furthermore, the data differentiates the data according to the salmons originating cohorts. Outtake data from salmon that were: released into seawater at some point the previous year, marked in purple (>1 yr cohort); released sometime the previous calendar year, marked in green (1 yr cohort); released the year in question, marked in blue (0 yr cohort). The amount is the whole fish equivalent of the slaughtered salmon ("rundvekt" in Norwegian).

Innrapportert uttak av laks til slakt per januar 2010. Antall i 1000 stk, og mengde i tonn rundvekt.

	Tidligere utsett		2009-utsett		2010-utsett	
Fylke	Antall	Mengde	Antall	Mengde	Antall	Mengde
Finnmark	852	4,146	0	0	0	0
Troms	1,397	8,419	0	0	0	0
Nordland	2,666	15,038	0	0	0	0
Nord-Trøndelag	934	5,138	0	0	0	0
Sør-Trøndelag	1,513	9,326	0	0	0	0
Møre og Romsdal	1,385	7,426	0	1	0	0
Sogn og Fjordane	885	4,482	0	0	0	0
Hordaland	1,941	9,138	42	142	0	0
Rogaland og Agder	1,410	6,768	0	0	0	0
Totalt	12,983	69,881	43	143	0	0

Figure D.1: Monthly outtake [tonnes] of salmon by county and cohort from 2010

The assumption is that when transporting live salmon, the necessary cargo volume per kg of salmon increases, the less the individual salmon weighs. This assumption is in line with the RSCPA standard (as indicated in Table 3.1). Obtaining the average weight of salmon onboard each LFC harvest transport in Norway is impossible with the public data set. The monthly data on county basis was used to obtain a rough estimate of the average weight of the individual salmon transported, using

$$w_{av}\,[kg] = \frac{w_{tot}\,[kg]}{x_{ind}}$$

, where W_{av} is the average weight of the individual salmon, W_{tot} is the total amount of salmon taken out for slaughter and X_{ind} is the number of individual salmon taken out for slaughter. This calculation was arranged into the tables, or matrices **D1.1-D1.11**. In Table **D1.1** (2009 data), e.g., the W_{av} of >1 yr cohort salmon in January, in Finnmark was 4.57 kg. As the counties Nord-Trøndelag and Sør-Trøndelag were joined into one county, Trøndelag, in 2018, the data before 2018 are combined. The total transported biomass for each month and county (marked in red in Figure **D.1**) was placed in equivalent matrices (tables **D2.1-D2.11**)

All average weight matrices were placed in a 24x132 matrix in Matlab (n = 24 represent all three cohorts in the eight counties, m = 132 represent all months in the period January 2009 to December 2019). The Matlab script is located the end of this appendix. The next step was to determine the appropriate transport stocking density for the salmon on a monthly and county basis. A simple if statement in Matlab determined the appropriate maximum stocking density (MSD) for each of the 24x132 entries in the average weight matrix formed the basis for an MSD conversion matrix, used for calculating the necessary cargo volume needed. The necessary LFC cargo volume was calculated using

$$V_{MSD}\left[m^3\right] = D_{MSD}\left[\frac{m^3}{kg}\right] \cdot W_{09-19}\left[kg\right]$$

, where V_{MSD} is a 24x132 matrix with the needed LFC cargo volume (adjusted by MSD), D_{MSD} is the stocking density conversion matrix and W_{09-19} is a 24x132 matrix consisting of tables **D2.1-D2.11**. All columns were summed up, generating a 1x132 matrix that indicates the estimated necessary LFC cargo volume needed each month in Norway (from January 2009 to January 2019). In the time series plot in Figure 7.1, this volume is the blue line.

Table D1.1: Average weight [kg] of individual salmon taken out for slaughter, on county basis in 2009. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
>1 yr cohort	**A**	4.57	5.37	4.87	5.70	7.03	6.62	3.72	4.74	5.08	5.42	5.82	6.63
	B	5.83	4.91	5.52	5.12	4.90	4.34	4.77	5.13	6.01	4.72	5.05	0.00
	C	5.66	5.89	5.51	4.82	4.55	4.67	4.91	4.79	5.05	8.00	9.15	0.00
	D	4.83	5.00	4.84	4.59	4.81	4.86	4.77	4.92	0.00	0.00	0.00	0.00
	E	5.67	5.19	4.87	4.76	4.66	4.70	4.01	0.00	5.34	4.53	4.71	4.17
	F	4.60	4.42	4.46	4.75	5.03	5.13	5.06	0.00	0.00	0.00	0.00	0.00
	G	5.08	4.97	4.70	4.58	4.81	4.89	5.24	5.87	0.00	0.00	0.00	0.00
	H	5.33	4.62	4.75	4.70	5.02	4.80	4.91	4.25	0.00	0.00	0.00	0.00
1 yr cohort	**A**	0.00	0.00	0.00	0.00	0.00	3.49	0.00	4.89	4.52	4.40	4.54	4.99
	B	0.00	0.00	0.00	0.00	1.42	2.39	3.12	4.78	5.06	5.25	5.80	5.74
	C	0.00	0.00	4.81	4.27	4.42	4.70	4.29	4.92	5.28	5.43	5.55	5.56
	D	0.00	0.00	0.00	0.00	3.45	4.03	4.61	4.74	5.01	5.25	5.56	5.50
	E	1.70	0.00	1.69	3.62	4.02	4.42	4.53	4.42	5.07	5.70	5.71	5.46
	F	0.00	0.00	0.00	2.87	4.05	4.35	4.30	4.37	4.42	5.00	5.77	5.48
	G	3.68	0.00	3.83	4.12	3.53	4.21	3.93	4.31	4.48	4.80	4.90	4.67
	H	0.00	0.00	0.00	0.00	4.10	4.00	4.31	4.38	4.50	5.02	5.45	5.09
0 yr cohort	**A**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.93	4.84
	B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.62	0.57	0.57	0.00	0.00
	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.35
	D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	E	0.00	0.00	0.00	0.00	0.00	0.00	0.53	0.00	0.00	0.00	0.00	2.00
	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	G	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.39	0.58	0.83	0.64	3.20
	H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D1.2: Average weight [kg] of individual salmon taken out for slaughter, on county basis in 2010. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
>1 yr cohort	**A**	4.86	5.34	5.11	5.23	5.16	5.41	4.98	4.76	5.01	5.72	6.18	6.57
	B	6.03	6.07	5.13	4.58	4.90	4.50	4.40	5.07	5.38	6.13	6.73	5.57
	C	5.64	5.83	5.32	4.82	4.94	5.01	5.43	5.68	6.78	5.13	0.00	0.00
	D	5.91	5.61	5.34	5.16	4.90	5.19	6.13	5.83	0.00	0.00	0.00	0.00
	E	5.36	4.69	4.87	5.00	4.93	4.89	5.40	4.59	4.46	0.00	11.80	0.00
	F	5.07	4.88	4.77	4.83	4.72	4.65	4.79	3.69	4.00	0.00	0.00	0.00
	G	4.71	4.64	4.86	4.98	5.08	5.38	6.14	4.69	0.00	0.00	0.00	0.00
	H	4.80	4.70	4.65	4.65	5.02	5.25	4.52	0.00	0.00	0.00	6.53	0.00
1 yr cohort	**A**	0.00	0.00	0.00	0.00	5.28	0.00	0.00	3.65	4.82	4.60	5.02	5.11
	B	0.00	0.00	0.00	0.00	0.49	1.50	2.27	4.83	4.99	5.39	5.73	6.06
	C	0.00	0.00	4.82	0.00	5.15	4.20	4.80	5.16	5.33	5.36	5.83	6.27
	D	0.00	0.00	0.00	0.00	0.00	3.95	4.19	4.67	5.00	5.13	5.46	5.41
	E	1.20	0.34	3.15	0.90	4.04	4.39	4.62	4.78	5.28	5.25	5.29	5.40
	F	0.00	0.00	0.00	2.52	4.02	3.92	4.31	4.42	4.75	5.24	5.70	5.12
	G	3.36	0.00	4.31	4.57	4.94	4.30	4.32	4.37	4.58	4.78	4.92	4.58
	H	0.00	2.68	0.00	0.00	0.00	0.00	3.88	4.02	4.35	4.31	4.69	4.87
0 yr cohort	**A**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	B	0.00	0.00	0.00	0.00	2.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	C	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00
	D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.00
	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.75
	G	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.38	0.52	0.00	0.46	0.26
	H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.05

Table D1.3: Average weight [kg] of individual salmon taken out for slaughter, on county basis in 2011. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
>1 yr cohort	**A**	6.06	5.87	6.07	6.20	5.91	7.17	5.35	6.22	6.17	6.11	6.91	6.15
	B	6.20	5.99	5.53	5.37	5.30	4.96	5.35	5.03	5.26	5.31	6.21	0.00
	C	6.46	5.63	5.46	4.92	5.27	5.27	5.40	5.36	5.66	0.00	0.00	5.48
	D	5.41	5.55	5.01	4.78	5.01	5.34	5.61	0.00	0.00	0.00	0.00	0.00
	E	5.60	5.31	5.22	5.28	5.14	5.80	5.79	5.67	6.27	4.92	13.64	4.98
	F	5.02	4.74	5.04	5.11	5.29	5.11	5.16	6.37	0.00	0.00	4.71	0.00
	G	4.82	4.82	5.13	5.25	5.27	5.49	5.48	5.18	0.00	0.00	0.00	0.00
	H	4.72	5.23	4.81	5.00	4.90	5.40	5.77	6.77	0.00	0.00	0.00	0.00
1 yr cohort	**A**	0.00	0.00	0.00	0.00	0.00	2.11	0.00	3.14	4.12	4.66	5.11	5.22
	B	0.00	0.00	0.00	0.00	0.00	2.38	4.23	4.60	4.86	5.03	5.60	5.80
	C	0.00	0.00	4.60	0.00	4.00	5.64	4.93	4.94	5.21	5.59	5.76	5.75
	D	0.00	0.00	0.00	4.14	4.01	0.00	4.93	4.74	4.98	5.31	5.38	5.36
	E	0.00	0.58	4.31	1.73	4.49	4.72	4.50	5.19	5.41	5.75	5.43	5.60
	F	0.00	2.67	0.00	3.93	5.49	4.34	4.76	4.55	4.86	5.29	5.25	5.65
	G	0.60	0.00	4.89	4.86	4.78	4.64	4.71	4.78	4.55	4.72	4.77	4.71
	H	0.00	0.00	0.00	0.00	0.00	4.05	3.87	3.75	4.05	4.96	5.05	4.87
0 yr cohort	**A**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.66	0.00	0.00
	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.52
	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	G	0.00	0.00	0.00	0.00	0.00	6.04	0.00	0.00	0.00	0.00	0.00	4.97
	H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D1.4: Average weight [kg] of individual salmon taken out for slaughter, on county basis in 2012. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
>1 yr cohort	**A**	6.16	5.69	6.10	5.82	5.82	5.57	5.26	5.85	5.38	5.57	6.33	0.00
	B	6.17	6.32	5.41	5.74	5.52	4.96	4.86	5.12	5.97	6.29	4.78	0.00
	C	6.34	6.12	5.55	4.93	4.64	4.76	5.10	5.21	6.49	0.00	0.00	0.00
	D	5.38	5.08	5.20	5.18	5.30	5.37	5.34	0.00	0.00	0.00	0.00	0.00
	E	5.41	5.06	4.82	4.67	4.90	5.77	5.74	4.34	5.29	5.07	0.00	0.00
	F	5.13	5.55	5.21	5.17	5.11	4.75	4.19	0.00	0.00	0.00	0.00	0.00
	G	4.86	5.06	4.56	4.70	5.11	5.43	6.06	0.00	0.00	0.00	0.00	0.00
	H	4.74	4.84	4.86	5.21	5.17	5.13	5.12	4.79	0.00	7.48	0.00	0.00
1 yr cohort	**A**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.11	3.48	4.48	4.79	4.94
	B	0.00	0.00	0.00	0.00	0.00	0.00	4.20	4.80	4.92	5.56	5.96	6.05
	C	0.00	0.00	0.00	3.68	1.70	4.56	4.31	4.71	4.97	4.95	5.18	5.11
	D	0.00	0.00	0.00	0.00	0.00	3.77	4.46	4.80	5.08	5.07	5.08	4.83
	E	0.00	0.26	0.35	3.85	4.33	4.29	4.41	4.82	4.80	5.18	5.57	5.79
	F	0.00	0.00	0.00	5.40	4.00	4.52	4.40	4.37	4.42	4.66	4.74	5.09
	G	6.30	0.00	4.37	4.24	4.33	4.64	4.56	4.68	4.79	5.28	5.31	5.10
	H	0.00	0.00	0.00	0.00	3.74	3.45	4.18	4.65	4.54	5.40	5.08	4.88
0 yr cohort	**A**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.78	5.39	4.86
	B	0.00	0.00	0.00	0.00	0.00	7.61	0.00	0.00	0.00	0.00	0.00	5.63
	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.00
	D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	E	0.00	0.00	0.00	0.00	0.06	0.21	0.37	0.00	0.39	1.00	0.15	0.40
	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	G	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.41	0.00	0.00
	H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D1.5: Average weight [kg] of individual salmon taken out for slaughter, on county basis in 2013. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
>1 yr cohort	**A**	5.02	5.14	5.00	4.74	4.71	4.75	4.72	5.38	5.60	5.31	7.46	0.00
	B	6.07	6.00	5.28	5.51	4.82	4.69	4.64	5.13	5.89	5.65	5.90	7.21
	C	5.44	5.09	5.12	5.11	5.04	5.35	5.79	5.83	4.49	5.35	6.23	5.57
	D	5.49	5.63	5.45	5.25	5.37	5.56	6.16	0.00	0.00	0.00	0.00	0.00
	E	5.45	5.71	5.64	5.47	5.43	5.90	6.03	4.66	12.34	0.00	0.00	0.00
	F	5.01	4.70	4.96	4.79	4.77	5.27	3.47	5.01	4.80	5.08	5.10	0.00
	G	4.98	4.72	4.32	4.98	5.14	5.05	6.11	3.60	0.00	4.45	5.54	0.00
	H	4.96	4.91	4.82	4.61	5.02	5.57	5.14	0.00	0.00	0.00	0.00	7.35
1 yr cohort	**A**	4.64	2.77	0.00	0.00	0.00	0.00	3.64	3.84	4.39	4.69	5.14	5.16
	B	0.00	0.00	0.00	4.51	2.94	3.01	4.12	4.31	4.71	5.05	4.90	5.34
	C	0.70	0.00	2.51	4.07	3.56	4.39	4.17	4.52	4.95	5.44	5.52	5.25
	D	0.00	0.00	2.64	0.00	0.00	4.03	4.13	4.36	4.56	4.74	4.69	4.45
	E	0.20	1.32	0.00	1.96	3.00	3.97	4.44	4.61	4.99	5.17	5.42	5.29
	F	0.00	4.23	3.51	4.60	4.81	3.51	4.39	4.52	4.77	5.17	5.04	4.88
	G	0.00	2.00	3.24	4.30	4.17	4.21	4.32	4.09	4.50	4.64	4.35	4.32
	H	0.00	0.00	0.00	0.00	4.38	3.20	3.99	4.35	5.20	4.74	5.03	4.54
0 yr cohort	**A**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.00	0.00	0.00
	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38	0.99	0.00
	D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34
	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.90
	G	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.18	3.71
	H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D1.6: Average weight [kg] of individual salmon taken out for slaughter, on county basis in 2014. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
>1 yr cohort	**A**	5.53	5.87	5.83	5.23	5.20	5.29	4.61	5.68	5.90	5.35	5.40	0.00
	B	5.20	5.21	4.72	4.53	4.50	5.07	4.96	5.33	4.94	0.00	0.00	0.00
	C	4.94	5.02	5.58	5.62	5.51	5.28	5.55	3.31	6.64	0.00	0.00	0.00
	D	4.62	5.06	5.27	5.62	5.73	6.09	0.00	0.00	0.00	0.00	0.00	0.00
	E	5.23	5.21	5.07	5.10	5.08	5.31	5.64	0.00	0.00	0.00	5.10	0.00
	F	4.70	4.56	4.82	5.18	5.46	4.60	0.00	0.00	0.00	0.00	0.00	0.00
	G	5.85	4.53	4.84	4.93	5.43	5.61	5.37	4.28	0.00	0.00	0.00	0.00
	H	5.02	4.88	5.17	5.17	5.15	5.51	5.73	0.00	0.00	0.00	0.00	0.00
1 yr cohort	**A**	0.00	0.00	0.00	0.00	0.00	5.28	4.36	3.94	4.30	5.08	5.42	5.53
	B	0.00	3.47	0.00	0.00	4.44	4.54	4.55	4.71	5.10	5.42	5.64	5.86
	C	2.28	2.19	0.00	4.76	4.51	4.44	4.58	4.70	5.02	5.35	5.81	5.33
	D	0.00	0.00	0.00	4.81	3.12	4.71	4.83	5.01	5.13	5.30	5.30	4.91
	E	0.43	0.30	4.03	0.54	0.39	4.63	4.48	4.51	4.73	4.84	5.23	5.97
	F	4.76	4.94	4.95	4.36	3.73	4.36	4.37	4.41	4.38	4.72	4.38	4.39
	G	3.93	4.59	4.28	4.23	4.48	4.57	4.53	4.27	4.20	4.38	4.46	4.38
	H	0.00	0.00	0.00	0.00	4.01	3.96	3.58	4.90	4.79	4.77	4.71	4.44
0 yr cohort	**A**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	4.00
	C	0.00	0.00	0.00	0.00	0.00	2.92	0.12	0.20	0.17	0.60	0.95	0.43
	D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	E	0.00	0.00	0.05	0.08	0.50	1.15	0.31	0.90	0.29	0.88	0.25	0.74
	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.69
	G	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.54	0.00	4.18
	H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D1.7: Average weight [kg] of individual salmon taken out for slaughter, on county basis in 2015. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
>1 yr cohort	**A**	5.72	5.42	4.66	5.38	4.42	5.05	5.36	4.95	5.40	0.00	0.00	0.00
	B	6.10	5.64	4.93	5.05	4.56	5.09	5.12	5.57	5.92	5.84	0.00	0.00
	C	5.07	5.23	5.05	5.29	5.60	5.44	6.57	5.91	0.00	0.00	0.00	0.00
	D	5.18	5.16	5.54	5.71	5.67	6.21	0.00	0.00	0.00	0.00	0.00	0.00
	E	5.92	5.56	5.80	5.80	6.51	6.99	10.15	8.07	11.11	8.96	12.32	0.00
	F	4.64	4.79	5.25	5.35	5.47	4.68	0.00	0.00	0.00	0.00	0.00	0.00
	G	4.75	5.08	5.31	5.56	5.75	6.16	6.67	0.00	0.00	0.00	0.00	0.00
	H	5.02	5.37	5.27	5.30	5.52	5.45	5.03	0.00	0.00	0.00	0.00	6.45
1 yr cohort	**A**	0.00	0.00	0.00	0.00	0.00	0.00	4.14	4.63	4.59	4.91	4.74	4.79
	B	0.00	0.00	0.29	0.74	0.00	4.09	3.97	4.41	4.80	5.12	5.45	5.57
	C	1.51	5.05	2.55	2.81	3.83	4.47	4.39	4.59	4.97	4.95	4.96	5.08
	D	0.00	0.00	0.00	0.00	4.61	4.47	4.25	4.71	4.72	4.16	4.63	4.59
	E	0.14	4.95	1.30	4.26	4.86	4.68	4.52	4.46	4.43	3.96	4.50	4.32
	F	4.47	4.43	3.94	4.48	4.43	4.20	4.90	4.77	4.88	4.89	5.10	5.26
	G	1.43	4.78	4.27	4.79	4.39	4.58	4.42	4.44	4.78	4.80	4.44	4.28
	H	0.00	0.00	0.00	3.58	4.03	4.18	3.83	4.35	4.47	4.69	4.66	4.43
0 yr cohort	**A**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.00	0.00	0.00	1.23
	C	0.00	0.00	0.00	0.00	0.20	0.43	0.43	0.40	0.43	0.44	0.61	0.46
	D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	E	0.20	0.21	0.17	0.25	0.18	0.16	0.33	0.27	0.47	0.38	1.00	0.53
	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	G	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.46	6.29	3.02
	H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D1.8: Average weight [kg] of individual salmon taken out for slaughter, on county basis in 2016. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
>1 yr cohort	**A**	4.94	5.03	5.09	4.54	5.68	5.51	5.63	6.08	6.35	6.30	0.00	0.00
	B	5.67	5.52	4.51	4.88	5.00	5.16	5.45	4.82	5.04	0.00	0.00	0.00
	C	5.02	4.98	5.06	5.28	5.56	5.35	4.57	4.44	4.44	3.61	2.73	0.00
	D	4.80	4.52	4.84	4.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	E	5.10	4.81	5.33	5.90	5.77	0.00	0.00	9.29	0.00	0.00	0.00	0.00
	F	4.88	5.26	5.39	5.13	5.52	5.16	0.00	0.00	0.00	0.00	0.00	0.00
	G	4.41	4.91	5.00	5.12	5.13	5.93	7.41	0.00	0.00	0.00	0.00	0.00
	H	4.62	4.78	5.20	5.49	5.87	5.66	6.19	0.00	0.00	6.42	0.00	0.00
1 yr cohort	**A**	0.00	0.00	0.00	0.00	0.00	1.94	0.00	4.06	4.24	4.98	5.17	5.59
	B	0.00	0.00	0.00	0.00	3.71	3.71	4.22	4.43	4.74	4.87	5.24	5.04
	C	1.98	1.49	3.27	2.71	4.70	4.60	4.17	4.47	4.80	4.58	4.50	4.24
	D	0.00	0.00	3.94	4.67	4.31	4.69	4.38	4.65	4.24	4.05	4.35	4.24
	E	0.29	2.88	3.54	4.79	4.45	4.22	5.07	5.03	4.32	4.31	5.04	5.28
	F	0.00	4.73	3.96	4.35	4.41	4.11	4.43	4.67	4.27	4.24	4.13	4.37
	G	1.38	4.14	1.96	4.24	4.28	4.31	4.35	4.44	3.81	4.39	3.97	4.54
	H	0.00	0.00	0.00	3.96	3.94	4.47	4.75	4.71	4.54	4.22	4.49	4.66
0 yr cohort	**A**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	C	0.00	0.00	0.00	0.00	0.00	0.17	0.22	0.43	0.91	0.89	0.54	2.41
	D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	E	0.05	0.00	0.25	0.00	0.55	8.66	0.17	0.30	0.18	0.29	0.24	1.91
	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.38
	G	0.00	0.00	0.00	0.00	0.00	4.86	4.64	4.74	4.79	0.00	0.00	4.56
	H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.44	0.00

Table D1.9: Average weight [kg] of individual salmon taken out for slaughter, on county basis in 2017. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
>1 yr cohort	**A**	5.44	5.25	5.42	4.47	4.76	4.43	4.68	5.19	5.45	5.09	0.00	0.00
	B	5.42	5.38	5.16	5.08	5.15	5.57	5.59	6.20	5.78	0.00	0.00	0.00
	C	4.90	4.84	4.86	5.20	5.46	5.97	5.36	5.88	0.00	0.00	0.00	0.00
	D	4.68	5.02	5.30	5.43	5.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	E	5.82	6.08	6.06	4.94	5.10	4.17	10.49	9.47	9.49	0.00	0.00	0.00
	F	4.79	5.11	5.23	4.92	4.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	G	4.94	5.56	5.62	5.80	5.95	6.75	5.66	3.80	3.99	0.00	0.00	6.54
	H	5.17	5.41	6.08	5.73	5.36	6.12	6.38	0.00	0.00	0.00	0.00	0.00
1 yr cohort	**A**	0.00	0.00	0.00	0.00	0.00	3.42	4.86	4.80	4.84	4.97	5.18	4.88
	B	0.00	4.69	4.63	5.58	4.87	4.91	4.74	4.53	4.83	4.74	5.05	5.08
	C	1.88	0.57	2.16	2.37	3.59	4.27	4.38	4.51	4.79	5.09	4.58	4.56
	D	0.00	0.00	3.71	4.03	4.27	4.60	5.03	4.94	4.40	4.66	4.56	4.58
	E	4.27	3.13	3.85	3.82	4.59	4.51	4.47	4.76	4.94	5.18	5.53	5.39
	F	4.44	4.94	3.02	4.63	3.32	3.93	4.22	4.37	4.51	4.83	5.01	4.91
	G	4.95	4.23	3.99	4.77	4.28	4.60	4.76	4.47	4.50	4.31	4.87	4.76
	H	0.00	0.00	0.00	4.36	5.39	3.92	4.02	4.46	4.12	4.13	4.91	4.90
0 yr cohort	**A**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	B	0.00	6.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.00
	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	3.48	0.00	0.38
	D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	E	0.00	0.00	0.00	0.00	0.09	0.42	0.56	0.60	0.31	2.32	0.23	0.21
	F	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.00	0.00	0.00	3.93	3.56
	G	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.40	3.26	4.36
	H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.62

Table D1.10: Average weight [kg] of individual salmon taken out for slaughter, on county basis in 2018. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
>1 yr cohort	**A**	4.83	5.78	5.97	5.28	5.52	5.20	5.12	5.83	5.80	4.77	0.00	0.00
	B	4.96	4.78	5.02	5.13	5.59	5.54	5.68	6.15	0.00	0.00	0.00	0.00
	C	4.64	4.94	5.14	4.87	5.39	5.49	5.90	6.79	7.35	20.83	6.42	0.00
	D	4.57	5.01	5.02	5.11	5.81	5.71	0.00	12.48	0.00	0.00	0.00	0.00
	E	4.98	4.83	4.60	4.92	4.18	6.64	0.00	0.00	0.00	0.00	0.00	0.00
	F	5.35	5.07	5.49	5.24	5.22	13.17	12.33	0.00	0.00	0.00	0.00	0.00
	G	5.00	4.76	5.01	4.55	4.51	5.39	5.68	0.00	0.00	4.46	0.00	0.00
	H	4.90	5.06	5.18	5.04	5.30	5.49	5.62	6.06	6.55	4.74	10.18	0.00
1 yr cohort	**A**	0.00	0.00	0.00	3.51	4.04	3.21	3.90	3.95	4.36	4.68	4.56	4.90
	B	3.90	5.44	5.72	5.87	3.94	3.57	4.08	4.18	4.87	5.30	5.53	5.50
	C	4.81	3.19	4.49	4.54	4.76	4.49	4.72	5.10	5.22	4.87	4.63	4.85
	D	5.15	4.22	4.40	4.53	4.27	4.95	4.98	5.00	4.56	4.75	4.80	4.47
	E	4.15	4.87	3.66	5.10	3.92	4.16	3.93	3.82	4.14	4.09	4.26	4.44
	F	4.36	4.18	4.63	4.87	4.47	4.48	4.69	4.66	4.27	3.83	3.73	4.29
	G	4.04	4.73	4.88	4.94	4.07	3.81	3.74	4.63	4.32	4.36	4.43	4.50
	H	4.35	3.89	4.53	4.62	4.40	4.57	4.70	4.77	4.73	4.65	4.64	4.74
0 yr cohort	**A**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	B	7.70	0.00	0.00	0.00	0.00	0.00	0.00	4.48	0.00	0.00	0.00	0.00
	C	0.00	0.00	0.00	0.00	0.00	0.20	4.69	0.01	0.25	0.00	0.00	0.00
	D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.73
	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.69	3.23
	F	0.00	0.00	0.00	0.00	0.00	0.00	3.92	0.00	0.00	0.00	3.60	3.33
	G	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	H	7.70	0.00	0.00	0.21	0.17	0.20	4.10	4.40	0.18	0.42	2.53	3.36

Table D1.11: Average weight [kg] of individual salmon taken out for slaughter, on county basis in 2019. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
>1 yr cohort	**A**	5.32	5.19	4.94	4.43	3.75	4.64	4.79	5.62	5.37	0.00	0.00	0.00
	B	5.34	5.16	4.84	4.96	4.66	5.21	5.12	5.23	0.00	0.00	0.00	0.00
	C	4.89	4.84	4.87	4.80	4.88	5.18	5.09	4.88	5.38	6.49	10.10	0.00
	D	4.88	5.06	5.17	5.26	5.64	15.36	13.14	11.40	0.00	0.00	9.91	0.00
	E	4.58	5.05	4.96	4.74	6.19	7.35	0.00	0.00	0.00	0.00	0.00	0.00
	F	4.60	4.41	4.79	4.90	5.39	6.09	6.10	0.00	0.00	0.00	0.00	0.00
	G	5.14	5.08	5.29	5.77	6.18	6.28	9.01	0.00	0.00	0.00	0.00	0.00
	H	4.99	4.98	4.98	4.98	5.00	5.50	5.01	5.41	5.38	6.49	9.99	0.00
1 yr cohort	**A**	0.00	0.00	0.00	0.00	0.00	1.80	0.00	3.95	4.08	4.45	4.26	4.48
	B	0.00	4.30	4.05	4.42	4.31	3.59	4.24	4.58	4.79	4.97	5.06	4.92
	C	0.54	0.96	4.42	4.70	4.76	4.55	4.53	4.60	5.00	5.07	5.06	5.10
	D	3.73	3.49	3.98	4.11	4.43	4.47	4.63	4.77	4.46	4.24	5.08	4.91
	E	4.46	4.76	4.26	4.20	3.85	4.42	3.78	3.96	4.15	4.35	4.18	4.47
	F	4.13	3.16	4.43	4.71	4.43	4.99	4.86	4.57	4.29	4.41	4.49	4.72
	G	0.00	0.00	4.78	4.05	4.57	4.08	5.15	4.55	4.33	4.07	4.31	4.70
	H	3.48	3.42	4.34	4.40	4.49	4.53	4.57	4.55	4.65	4.68	4.72	4.78
0 yr cohort	**A**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.66
	C	0.00	0.00	0.00	0.00	0.00	0.00	0.37	4.90	5.32	4.60	7.26	4.16
	D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.62
	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.05	2.66	2.80
	F	0.00	0.00	0.00	0.00	2.85	0.00	0.00	0.51	4.55	1.66	2.24	4.22
	G	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.59	0.00	0.00
	H	0.00	0.00	0.00	0.00	2.85	0.00	0.32	4.33	5.04	4.26	3.71	3.90

Table D2.1: Production volume [tonnes] taken out for slaughter, on county basis in 2009. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
>1 yr cohort	**A**	2916.56	3716.67	3404.53	1899.23	1168.35	1501.51	116.38	1279.50	1581.75	947.04	1090.43	923.41
	B	7668.01	4635.38	8602.79	6463.43	4631.82	4462.44	4418.06	2433.38	4247.88	2025.78	90.86	0.00
	C	11141.76	11153.42	10219.87	6481.25	11096.52	9561.91	9265.67	6971.28	1277.76	40.00	100.00	0.00
	D	6682.42	5502.57	9306.80	8428.69	8908.90	5955.00	2055.47	1307.63	0.00	0.00	0.00	0.00
	E	5431.35	5644.19	5732.33	8413.79	6322.04	6287.69	944.02	0.00	370.05	360.49	334.00	313.17
	F	5619.74	3259.85	3709.24	3792.22	3331.68	3648.05	4952.42	0.00	0.00	0.00	0.00	0.00
	G	7584.73	9777.58	11333.05	9002.86	8248.22	8648.28	4004.79	789.56	0.00	0.00	0.00	0.00
	H	5028.92	3375.86	5399.08	8812.77	7167.80	7913.33	2982.00	212.13	0.00	0.00	0.00	0.00
1 yr cohort	**A**	0.00	0.00	0.00	0.00	0.00	267.17	0.00	130.13	1710.91	3015.37	2954.39	2434.85
	B	0.00	0.00	0.00	0.00	1019.35	428.43	382.02	4363.71	7725.08	9522.05	13190.32	10384.10
	C	0.00	0.00	379.92	914.57	1691.39	2747.28	3068.66	9070.37	14763.47	17346.39	17186.50	17718.24
	D	0.00	0.00	0.00	492.21	762.14	958.28	2995.13	7384.41	10141.54	10673.48	10499.15	8714.16
	E	0.74	0.00	1.58	185.02	602.90	2017.65	6608.21	11695.72	10008.00	7570.18	10258.11	12586.80
	F	0.00	0.00	0.00	80.80	748.14	1764.61	4388.25	5798.45	5718.80	8461.00	5493.39	5778.09
	G	119.63	0.00	975.05	1196.94	2076.00	5446.13	11732.89	11430.09	12506.64	9845.18	11040.26	13509.62
	H	0.00	0.00	0.00	0.00	367.19	1020.49	3159.58	3497.31	3953.53	4979.14	7658.58	7630.34
0 yr cohort	**A**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	23.99	488.46
	B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	92.00	120.00	356.00	0.00	0.00
	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	569.86
	D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	E	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.24
	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	G	0.00	0.00	0.00	0.00	0.00	0.00	0.48	0.50	0.80	0.40	1.40	71.12
	H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D2.2: Production volume [tonnes] taken out for slaughter, on county basis in 2010. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
>1 yr cohort	**A**	4145.83	5176.09	4975.72	3833.19	2063.83	1623.55	1524.33	4621.18	4999.74	2817.14	1869.99	1475.16
	B	8419.45	6028.73	6058.20	4577.44	5149.16	6248.86	4753.74	6406.67	5372.19	1920.27	1147.94	503.71
	C	15037.81	13168.99	17167.75	11453.77	8999.79	11485.55	7377.17	2038.36	156.00	37.47	0.00	0.00
	D	14463.83	16014.43	14828.89	14728.21	12086.42	19977.67	6679.36	1364.45	0.00	0.00	0.00	0.00
	E	7426.40	3699.73	8671.45	6607.12	9735.08	8208.79	6205.80	2612.64	320.21	0.00	20.79	0.00
	F	4482.34	4041.51	8209.64	5716.59	7893.18	4839.64	1734.99	121.74	335.91	0.00	0.00	0.00
	G	9138.17	10008.97	10371.88	6691.07	12184.99	9208.22	6312.18	201.13	0.00	0.00	0.00	0.00
	H	6767.50	5708.43	8799.88	7880.61	8308.57	8895.22	2126.88	0.00	0.00	0.00	13.08	0.00
1 yr cohort	**A**	0.00	0.00	0.00	0.00	243.28	0.00	0.00	201.66	676.87	2990.44	4233.83	2611.95
	B	0.00	0.00	0.00	0.00	45.09	492.12	2134.07	6476.22	7427.24	10043.94	11979.38	8543.98
	C	0.00	0.00	202.78	0.00	291.23	2159.99	4619.18	12511.30	18885.43	19746.42	19642.17	17905.78
	D	0.00	0.00	0.00	66.91	232.47	1163.18	3758.53	8671.72	19814.57	19196.88	20224.38	15507.57
	E	0.57	0.40	1.70	1.62	125.05	1280.95	3347.16	6015.60	8674.84	12017.50	11608.10	10606.77
	F	0.00	0.00	0.00	166.26	641.71	2438.12	5753.65	7728.47	5873.12	6957.54	6834.84	5951.60
	G	142.43	0.00	575.93	928.77	2534.73	8669.60	12123.55	9710.66	8672.60	6171.70	11088.65	14176.43
	H	0.00	111.54	0.00	0.00	0.00	0.00	2193.53	2319.57	3446.79	4370.04	4645.80	6147.13
0 yr cohort	**A**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	B	0.00	0.00	0.00	0.00	212.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	C	0.00	0.00	0.00	0.00	0.00	0.00	3.26	0.00	0.00	0.00	0.00	0.00
	D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.00
	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	266.20
	G	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.60	0.35	0.00	0.50	0.55
	H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	64.42

Table D2.3: Production volume [tonnes] taken out for slaughter, on county basis in 2011. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
>1 yr cohort	**A**	5779.24	5658.42	3767.28	3862.65	4595.08	1776.49	478.06	2206.94	3687.13	4189.18	5082.09	1560.40
	B	7856.06	7151.16	8704.31	5592.77	6204.52	7109.79	8738.33	6618.89	5267.15	2207.05	865.21	0.00
	C	13986.65	10412.32	12845.58	5755.77	13127.60	14273.03	7073.10	8865.08	477.31	0.00	0.00	44.19
	D	12315.87	13749.53	13704.67	11838.95	20519.48	13404.66	14583.79	3439.06	0.00	0.00	0.00	0.00
	E	10374.75	7885.69	11669.67	6911.44	4788.86	4141.30	4678.46	3887.66	1064.20	220.69	89.46	10.11
	F	4865.84	3474.51	5923.65	7512.28	10142.44	6778.38	185.13	685.45	0.00	0.00	43.62	0.00
	G	11730.87	11120.87	13453.21	9697.28	9427.26	10751.50	6886.81	889.02	0.00	0.00	0.00	0.00
	H	5033.03	4976.22	5439.61	7523.73	8771.30	7765.26	7038.32	573.55	0.00	0.00	0.00	0.00
1 yr cohort	**A**	0.00	0.00	0.00	0.00	0.00	38.97	0.00	485.91	1273.50	3818.75	2222.97	4216.64
	B	0.00	0.00	0.00	0.00	0.00	949.54	621.47	1171.85	6938.66	9802.12	12664.74	10240.90
	C	0.00	0.00	391.13	0.00	90.97	1953.40	2508.78	8504.31	18673.21	19287.36	21627.09	17686.28
	D	0.00	0.00	51.68	1716.79	452.47	2810.18	3881.40	14474.42	20758.93	20536.00	22100.09	25019.72
	E	0.00	3.15	114.52	2.76	69.53	1359.88	2294.91	9581.63	12899.75	15747.11	16218.35	10510.64
	F	0.00	231.80	0.00	147.00	595.00	1517.13	5460.79	6054.08	7049.55	9321.03	7593.65	9709.53
	G	0.65	0.00	594.71	446.02	2094.55	6206.66	9319.84	11524.87	10343.55	9836.12	14590.64	15351.26
	H	0.00	0.00	0.00	0.00	0.00	1037.81	209.64	4871.55	5760.60	4865.64	4847.95	6212.03
0 yr cohort	**A**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	127.01	0.00
	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.11
	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	G	0.00	0.00	0.00	0.00	0.00	7.07	0.00	0.00	0.00	0.00	0.00	350.97
	H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D2.4: Production volume [tonnes] taken out for slaughter, on county basis in 2012. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
>1 yr cohort	**A**	5149.64	7280.24	6444.38	5016.39	5940.98	5676.79	4460.98	5137.13	6311.52	2768.12	1673.40	0.00
	B	9116.34	7862.54	7397.50	6474.30	8888.60	8940.32	6238.34	4579.22	4556.38	2489.68	491.56	0.00
	C	19146.13	14792.26	15363.68	13934.58	12625.38	15896.50	14374.96	5348.54	1120.37	0.00	0.00	0.00
	D	14329.16	18590.89	24033.46	14529.08	14873.34	18065.61	3477.89	0.00	560.59	0.00	0.00	0.00
	E	10982.98	5122.74	11623.08	8894.27	9595.42	7994.36	4011.92	3409.47	730.58	117.45	0.00	0.00
	F	5016.22	7247.12	13290.80	9975.27	10363.05	6011.28	747.25	0.00	0.00	0.00	0.00	0.00
	G	13426.38	11039.13	10181.16	10742.71	12585.48	6376.41	4666.36	0.00	0.00	0.00	0.00	0.00
	H	5617.33	6740.66	10930.87	9066.54	9828.10	9480.97	7361.12	667.82	0.00	20.54	0.00	0.00
1 yr cohort	**A**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	206.10	1588.27	5475.75	5709.77	5884.37
	B	0.00	0.00	0.00	0.00	0.00	0.00	1120.15	6635.75	8337.96	13155.78	16273.82	14676.52
	C	0.00	0.00	0.00	365.39	2.55	1854.84	5786.36	16815.43	21494.78	23963.45	20411.27	18331.64
	D	267.47	0.00	0.00	0.00	2286.81	1308.05	12738.03	23955.94	28491.98	28766.43	23797.62	20004.13
	E	0.00	0.63	0.76	19.50	1130.84	1309.98	6614.57	8764.53	7669.39	9332.60	12198.55	9689.58
	F	0.00	0.00	0.00	487.42	1046.39	1723.41	4243.42	6019.92	8030.80	9678.21	7697.25	5075.96
	G	234.78	0.00	953.90	1986.63	5634.30	9664.37	19611.22	19875.10	14619.47	15747.67	21471.20	18480.59
	H	0.00	0.00	0.00	0.00	1437.13	1300.94	1466.38	3013.12	2990.52	6844.39	5255.58	6430.67
0 yr cohort	**A**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	43.09	679.47	523.67
	B	0.00	0.00	0.00	0.00	0.00	1068.87	0.00	0.00	0.00	0.00	0.00	162.61
	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
	D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	E	0.00	0.00	0.00	0.00	0.11	0.83	0.21	0.00	0.73	12.35	0.04	0.16
	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	G	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	537.17	0.00	0.00
	H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D2.5: Production volume [tonnes] taken out for slaughter, on county basis in 2013. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
>1 yr cohort	**A**	8371.65	7490.70	8019.51	5272.29	8137.94	6977.72	2831.77	4369.11	4209.02	3230.93	1169.67	0.00
	B	12468.89	7078.07	7666.00	8298.02	9360.31	7584.32	7694.03	4988.66	1718.53	685.18	681.98	511.22
	C	16049.51	13461.86	15262.75	13262.03	9536.85	10499.04	5216.24	1223.91	16.64	527.31	371.80	243.14
	D	21684.64	17141.15	18371.16	20710.86	19303.44	18483.75	1018.14	34.59	371.60	0.00	0.00	0.00
	E	4919.64	5214.60	8268.64	4739.17	4622.30	4758.38	1152.66	6.20	31.05	0.00	0.00	0.00
	F	4313.35	6269.00	7964.36	10138.73	9693.97	6542.95	170.15	314.00	43.90	143.44	131.48	0.00
	G	13389.50	9271.06	9148.73	11520.92	11236.15	7522.51	2453.60	436.95	0.00	262.66	261.86	0.00
	H	6478.24	6631.18	8738.95	8210.48	9753.55	9448.97	4337.70	0.00	0.00	0.00	0.00	10.79
1 yr cohort	**A**	1497.93	1758.98	0.00	0.00	0.00	0.00	1392.65	2373.59	2594.96	4834.31	4881.60	7441.73
	B	0.00	0.00	0.00	303.29	1538.62	46.53	1719.73	5536.98	13149.49	16438.92	16764.27	12663.70
	C	0.01	0.00	401.49	2279.98	2517.91	3219.09	7590.33	19093.80	25738.36	31578.90	25397.42	19717.84
	D	0.00	0.00	648.77	0.00	125.79	1446.93	11717.92	18414.14	25767.78	24344.78	17698.49	10817.17
	E	1.06	6.12	0.00	1.15	91.46	3822.18	13698.55	13020.94	15768.30	13941.79	15175.88	17245.48
	F	0.00	146.39	446.78	242.39	585.22	1140.47	4836.76	8818.45	8854.65	10692.72	10206.91	10622.18
	G	0.00	76.29	400.20	580.15	3526.98	7450.54	17135.51	10815.53	12165.70	12665.40	11807.16	11707.53
	H	0.00	0.00	0.00	0.00	255.74	1149.61	4526.83	4489.31	2525.61	3553.70	8448.60	8176.04
0 yr cohort	**A**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.00
	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	105.57	0.00
	D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.95
	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.41
	G	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	195.80	330.21
	H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D2.6: Production volume [tonnes] taken out for slaughter, on county basis in 2014. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
>1 yr cohort	**A**	8258.73	9142.25	10700.16	10140.06	5260.81	6402.66	4314.86	3092.36	3654.06	1107.36	71.26	0.00
	B	14177.66	9763.30	10956.05	8302.70	12107.57	9548.90	5641.73	3601.93	119.26	0.00	0.00	0.00
	C	14712.80	10273.64	15197.44	18480.19	14536.13	9773.68	5388.57	270.98	122.55	0.00	0.00	0.00
	D	17344.83	17174.40	12987.32	9700.31	13415.34	15205.76	153.62	0.00	0.00	0.00	0.00	0.00
	E	7651.09	7576.21	12450.60	17696.63	16950.72	13489.38	2670.68	0.00	0.00	0.00	0.35	0.00
	F	6260.16	4624.28	12506.80	10010.17	4062.08	2083.08	0.00	0.00	0.00	0.00	0.00	0.00
	G	15603.75	10302.25	10503.81	8479.14	8559.64	8675.17	1960.91	80.92	0.00	0.00	0.00	0.00
	H	7767.88	7500.54	8407.64	9028.34	8530.80	7302.80	2351.98	0.00	0.00	0.00	0.00	0.00
1 yr cohort	**A**	0.00	0.00	0.00	0.00	0.00	60.84	546.83	2874.53	5160.04	9091.52	11737.27	9364.61
	B	0.00	414.83	0.00	0.00	420.20	1494.00	2018.82	8711.16	14289.45	13514.48	13206.69	16534.90
	C	205.00	449.00	0.00	1772.08	1508.16	9049.74	9885.02	20000.77	26773.08	28184.17	24151.49	14850.86
	D	0.00	139.30	2700.09	307.64	3508.21	1688.44	26595.95	32745.61	33386.97	39489.23	28052.36	25229.90
	E	1.82	0.20	95.51	0.65	0.28	1161.66	6241.99	5922.53	8145.25	6784.60	6388.15	6225.68
	F	323.80	591.50	210.37	1554.65	2473.56	5245.21	9296.51	8516.49	6768.54	6921.15	6934.15	8418.70
	G	176.50	1008.01	833.53	4327.94	7270.94	9281.51	19063.17	14689.70	15524.43	12659.45	10124.61	12536.78
	H	0.00	0.00	0.00	0.00	831.73	1949.84	2060.40	2267.66	1633.63	3516.66	5287.89	7583.10
0 yr cohort	**A**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.04
	C	0.00	0.00	0.00	0.00	0.00	61.73	0.04	0.22	0.01	208.36	336.71	0.19
	D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	E	0.00	0.00	0.00	0.00	0.74	1.30	0.54	146.24	16.20	0.97	0.66	3.73
	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	269.84
	G	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	271.36	0.00	342.91
	H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D2.7: Production volume [tonnes] taken out for slaughter, on county basis in 2015. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
>1 yr cohort	**A**	9278.49	8828.96	6805.72	7067.72	2263.95	2902.69	3530.11	4212.17	3293.67	0.00	0.00	0.00
	B	12337.93	8418.05	9387.50	9356.85	8450.34	14409.24	10060.62	7886.69	369.58	12.09	0.00	0.00
	C	20492.72	12258.33	19076.46	20021.17	17567.54	7812.73	743.04	616.92	0.00	0.00	0.00	0.00
	D	18390.64	26216.24	34696.31	24166.88	17189.27	19503.74	591.30	0.00	0.00	0.00	0.00	4.36
	E	5463.11	4097.92	5672.77	2756.28	2184.93	1291.16	76.11	86.40	18.57	20.22	1.00	0.00
	F	6685.68	5910.47	9743.14	9291.32	6833.06	367.23	0.00	0.00	0.00	0.00	0.00	0.00
	G	10564.05	9353.39	10718.74	10239.02	10674.58	6453.51	1115.99	0.00	0.00	0.00	0.00	0.00
	H	7440.63	8449.27	11675.88	10236.79	12775.14	9848.86	3059.83	0.00	0.00	0.00	0.00	22.77
1 yr cohort	**A**	0.00	0.00	0.00	0.00	0.00	0.00	730.36	1540.00	5941.40	7973.63	10104.21	9191.89
	B	0.00	0.00	0.08	0.13	0.00	660.39	1880.12	6342.67	11509.00	16577.77	16712.76	19228.13
	C	454.91	402.74	712.27	1064.84	2815.99	5963.34	15384.85	19339.62	29987.47	26188.00	25060.42	15841.24
	D	0.00	494.56	583.84	1058.45	4780.73	13661.83	13021.77	15196.12	13139.49	18554.29	10631.80	13766.45
	E	0.04	116.14	1.11	1092.92	4054.71	10533.87	17844.50	27239.16	33428.09	25213.59	18878.33	10412.38
	F	184.48	471.40	384.75	841.41	2891.40	6668.22	8772.67	6633.28	7045.71	7220.30	9158.23	10791.29
	G	558.57	641.57	1620.75	3424.84	4731.86	10272.95	14090.06	5987.43	9396.82	15956.33	14344.26	11847.22
	H	0.00	0.00	0.00	114.38	618.22	2160.43	2051.61	3890.56	2405.50	1681.81	7341.21	10075.74
0 yr cohort	**A**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	299.13	0.00	0.00	0.00	106.00
	C	0.00	0.00	0.00	0.00	68.60	19.40	19.35	410.51	19.35	25.83	176.91	26.91
	D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	E	0.14	0.41	0.12	0.48	0.11	0.86	0.75	2.47	0.62	1.12	4.86	1.62
	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	G	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	255.74	524.36	1627.50
	H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D2.8: Production volume [tonnes] taken out for slaughter, on county basis in 2016. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
>1 yr cohort	**A**	10356.57	9252.39	11181.64	7055.29	4317.05	4005.40	2334.02	3186.30	4089.04	2140.37	0.00	0.00
	B	15242.40	13162.44	11436.50	13773.14	15946.76	9788.86	7180.45	2458.60	1070.37	0.00	0.00	0.00
	C	16129.67	9953.87	16210.76	16865.23	20262.82	8066.18	1514.48	51.37	51.37	25.42	38.71	0.00
	D	8474.32	10116.32	13458.03	13152.73	5316.21	4635.77	0.00	0.00	0.00	0.00	0.00	0.00
	E	11514.37	11187.88	9297.05	5843.74	1190.42	0.00	0.00	68.77	0.00	0.00	0.00	0.00
	F	8428.45	10708.18	9871.29	5358.00	1307.69	579.81	0.00	0.00	0.00	0.00	0.00	0.00
	G	9966.67	10691.66	11715.76	9440.57	6716.28	1795.90	45.31	0.00	0.00	0.00	0.00	0.00
	H	6591.42	7110.57	9221.63	9716.08	9929.64	4937.33	494.74	0.00	0.00	7.18	0.00	0.00
1 yr cohort	**A**	0.00	0.00	0.00	0.00	0.00	294.03	0.00	3007.96	4192.27	4952.83	12034.34	10599.02
	B	0.00	0.00	0.00	0.00	193.96	905.25	1428.75	10566.78	12802.46	16900.32	22739.66	14264.55
	C	196.97	545.94	660.22	2042.22	1670.74	8350.97	18913.55	19830.47	29762.26	29948.35	23222.18	13201.55
	D	0.00	1258.56	1434.60	8277.43	14102.03	9773.59	18556.91	37707.15	34007.37	17754.96	17642.83	18164.00
	E	0.69	176.54	129.84	318.02	1833.59	4512.65	6637.43	6101.81	7486.52	7303.85	4494.73	5978.60
	F	0.00	725.66	535.18	916.01	2617.25	4489.43	4932.27	9743.00	5332.76	10146.76	10163.31	7161.32
	G	767.23	1197.90	1458.26	2739.22	7742.67	15800.40	17307.54	14205.03	15247.12	14976.51	14541.65	12750.19
	H	0.00	0.00	0.00	742.72	2228.47	790.16	2200.10	1682.41	5481.48	5092.71	9460.13	11872.96
0 yr cohort	**A**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	C	0.00	0.00	0.00	0.00	0.00	0.02	0.04	1.38	0.22	0.94	0.42	1238.68
	D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	551.00	0.00	0.00	0.00
	E	0.12	0.00	0.02	0.00	1.68	37.53	0.05	0.05	0.21	0.82	0.21	345.25
	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	695.60
	G	0.00	0.00	0.00	0.00	0.00	98.95	588.10	341.51	402.59	0.00	0.00	678.91
	H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00

Table D2.9: Production volume [tonnes] taken out for slaughter, on county basis in 2017. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
>1 yr cohort	**A**	9952.84	8109.06	7236.54	2234.16	2260.90	1857.38	2063.66	10399.08	3517.33	1712.61	0.00	0.00
	B	10763.04	9234.34	12828.45	12112.78	16920.23	18576.83	5288.59	4167.86	952.34	0.00	0.00	0.00
	C	10970.36	11988.63	16391.48	12132.19	11004.16	4217.53	1828.68	1275.07	0.00	0.00	0.00	0.00
	D	20602.12	24618.46	31604.99	20915.91	8282.20	21868.40	0.00	0.00	0.00	0.00	0.00	0.00
	E	3240.51	3633.81	3864.88	1011.29	766.66	913.23	84.43	219.02	119.78	0.00	0.00	0.00
	F	7145.96	8553.04	5421.13	9007.28	4117.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	G	9297.30	9549.36	10714.20	10205.21	3926.42	2109.80	295.94	573.42	717.03	0.00	0.00	109.50
	H	12161.71	8075.36	12710.14	10157.79	7649.66	3094.77	529.51	0.00	0.00	0.00	0.00	0.00
1 yr cohort	**A**	0.00	0.00	0.00	0.00	0.00	134.98	140.99	760.45	6195.08	11788.44	15955.94	11762.38
	B	0.00	352.49	739.99	206.81	1811.27	2423.35	7307.65	19200.13	22997.21	21098.49	16896.23	13250.24
	C	2823.49	31.05	245.62	1.47	5553.77	9284.84	13358.71	23622.27	33672.85	34375.82	21803.82	23489.18
	D	364.14	3018.04	3266.54	3354.20	5925.07	7265.27	10582.46	10619.65	4543.19	10308.06	9654.44	11373.00
	E	305.63	298.38	1402.71	761.19	6609.70	10738.53	21639.89	19899.85	23376.18	23958.05	26245.34	16621.96
	F	172.89	985.46	993.12	1109.84	4051.92	5408.06	6224.29	7587.19	7313.39	7957.69	6630.50	11845.66
	G	1782.59	1260.01	2192.93	4596.27	10613.79	12702.43	16777.99	11993.10	11384.19	10093.82	13073.74	12552.08
	H	0.00	0.00	0.00	381.62	233.63	3347.04	4888.62	3151.60	3235.71	6525.47	10259.29	7632.25
0 yr cohort	**A**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	B	0.00	484.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	30.00	0.00
	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.94	0.00	0.01
	D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	141.94	246.86
	E	0.00	0.00	0.00	0.00	0.06	0.03	0.44	0.83	0.60	102.87	0.25	0.50
	F	0.00	0.00	0.00	8.20	0.00	0.00	0.00	0.00	0.00	0.00	421.93	582.01
	G	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	679.75	316.76	997.16
	H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	393.66

Table D2.10: Production volume [tonnes] taken out for slaughter, on county basis in 2018. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
>1 yr cohort	**A**	13348.82	10049.16	10265.45	6267.52	3935.64	5448.50	3771.80	3861.95	1290.80	1921.63	0.00	0.00
	B	9084.81	9701.93	10807.98	14846.75	16337.33	12193.62	2845.35	73.98	0.00	0.00	0.00	0.00
	C	24246.07	13930.74	11022.71	10311.84	17329.31	6461.85	6205.54	902.81	501.78	61.73	1.15	0.00
	D	10628.95	14408.99	16911.52	12280.75	3107.39	2343.58	0.00	17.74	0.00	0.00	0.00	0.00
	E	12789.86	8950.44	9276.35	4749.24	2850.56	1568.98	0.00	106.17	331.09	0.00	12.20	0.00
	F	7906.47	6734.66	7649.22	6502.25	1781.28	694.85	0.00	0.00	0.00	0.00	0.00	0.00
	G	13246.48	9261.83	9486.69	9549.14	1780.32	137.90	59.98	0.00	0.00	0.00	0.00	0.00
	H	8709.16	6341.65	7002.81	5913.47	6636.63	4062.48	481.86	0.00	0.00	1011.40	0.00	0.00
1 yr cohort	**A**	0.00	0.00	0.00	761.93	1258.13	756.83	1464.09	3097.10	4669.73	11319.55	14363.48	9714.87
	B	1237.96	337.08	1441.66	2069.88	1639.87	577.00	6115.64	10791.62	18042.75	25484.76	20527.00	17356.01
	C	916.89	2824.77	4894.88	3961.10	12669.71	10732.94	19082.36	32599.31	28964.23	16051.21	19684.47	18236.21
	D	594.24	2055.14	2442.17	7056.57	14333.13	27774.71	39306.86	38199.72	28914.09	39159.55	33007.03	25997.54
	E	0.27	0.14	0.08	145.60	2165.98	2228.57	3590.48	5417.29	6680.32	7083.78	3081.08	5763.51
	F	86.68	388.46	1397.16	1220.32	954.50	3458.82	4954.85	6473.91	5341.83	11625.53	6459.83	4513.36
	G	1600.98	3702.62	5046.25	4151.41	10675.28	16366.11	19403.79	17018.44	10012.74	12719.50	13302.47	11383.90
	H	420.98	139.62	470.92	352.55	2224.16	4012.43	799.08	1458.31	2087.70	5445.79	10813.31	12013.03
0 yr cohort	**A**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	B	344.96	0.00	0.00	0.00	0.00	0.00	0.00	96.48	0.00	0.00	0.00	0.00
	C	0.00	0.00	0.00	0.00	0.00	0.00	228.96	0.00	0.17	0.00	0.00	0.00
	D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	333.16
	E	0.00	0.00	0.00	0.09	0.11	0.00	0.00	0.00	0.61	0.35	1181.32	0.00
	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	112.08	484.97
	G	0.00	0.00	0.00	0.00	0.00	0.00	662.62	0.00	0.00	0.00	37.62	1659.82
	H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D2.11: Production volume [tonnes] taken out for slaughter, on county basis in 2019. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
>1 yr cohort	A	10509.15	6342.71	6726.53	5816.37	4716.13	6333.00	9702.08	5722.92	5600.47	0.00	0.00	0.00
	B	15140.96	14088.89	12135.88	12966.03	15477.19	6652.60	3225.54	2987.23	0.00	0.00	0.00	0.00
	C	17248.99	19435.72	19673.06	20919.68	11674.54	5681.73	3936.07	2514.49	4522.82	839.09	10.24	0.00
	D	24609.80	21807.41	18050.79	14584.85	4811.20	516.84	357.86	27.31	0.00	0.00	12.31	0.00
	E	4450.27	2607.35	1794.00	1195.32	843.10	153.85	19.28	325.48	0.00	0.00	0.00	0.00
	F	7353.05	9108.45	6540.06	7444.77	212.96	1346.82	0.00	0.00	0.00	0.00	0.00	0.00
	G	9149.77	7604.83	7949.78	7982.16	2755.27	2021.06	492.33	0.00	0.00	0.00	0.00	0.00
	H	9846.62	10863.28	9372.08	11616.90	11690.98	7403.51	15.86	0.00	0.00	0.00	0.00	0.00
1 yr cohort	A	0.00	0.00	0.00	0.00	0.00	130.28	0.00	6010.03	7849.83	15917.33	16796.84	11277.41
	B	0.00	409.29	628.62	539.44	1190.04	2914.03	5700.19	11701.15	21109.80	15692.54	17853.64	15535.17
	C	0.49	0.36	1457.19	2027.26	8812.54	15323.62	23000.84	35775.72	31914.88	37839.74	26562.96	21020.21
	D	357.29	351.08	1927.82	5075.82	10525.74	13837.32	16436.44	18793.70	17268.22	16666.70	9142.89	7956.10
	E	4989.91	935.08	1153.53	5422.34	18818.01	17801.41	18470.68	21387.64	26762.42	27048.20	16505.20	9635.17
	F	280.63	425.33	1974.61	2737.68	3383.08	4751.67	6702.35	5026.82	6802.23	10999.27	9661.10	8526.89
	G	3249.51	2407.29	4655.31	5197.44	7684.99	11017.23	22995.51	15422.51	10047.97	10976.62	8143.66	14017.98
	H	0.00	0.00	2615.80	2686.92	748.57	2901.62	1018.34	1967.61	4093.75	8994.76	14251.69	13067.98
0 yr cohort	A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	602.17
	C	0.00	0.00	0.00	0.00	0.00	0.00	0.09	95.25	856.72	594.96	504.68	614.34
	D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	483.37
	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.40	0.02	0.00	151.53	573.09
	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.33	64.57	69.70
	G	0.00	0.00	0.00	0.00	113.12	0.00	0.00	0.09	404.76	42.66	353.13	2106.94
	H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	477.51	0.00	0.00

```
close all;
clear all;


%%%LOAD OUTTAKE DATA IN LWE%%%
% Load average weight data in LWE (rundvekt)
% Tables D1.1-D1.11 in Appendix D

AW_09 = importdata('AW_2009.txt');
AW_10 = importdata('AW_2010.txt');
AW_11 = importdata('AW_2011.txt');
AW_12 = importdata('AW_2012.txt');
AW_13 = importdata('AW_2013.txt');
AW_14 = importdata('AW_2014.txt');
AW_15 = importdata('AW_2015.txt');
AW_16 = importdata('AW_2016.txt');
AW_17 = importdata('AW_2017.txt');
AW_18 = importdata('AW_2018.txt');
AW_19 = importdata('AW_2019.txt');

WFE = 1.067; % Conversion ratio whole fish equivalent (WFE) to live weight...
             % according to NS 9417:2012

% Put all average weight data in a 24x132 matrix. Converting with WFE for live fish ...
    weight

AW_all = [AW_09, AW_10, AW_11, AW_12, AW_13, ...
          AW_14, AW_15, AW_16, AW_17, AW_18, AW_19] *WFE;

% Load total outtake data in LWE (rundvekt)
% Tables D2.1-D2.11 in Appendix D

OT_09 = importdata('Uttak_2009.txt');
OT_10 = importdata('Uttak_2010.txt');
OT_11 = importdata('Uttak_2011.txt');
OT_12 = importdata('Uttak_2012.txt');
OT_13 = importdata('Uttak_2013.txt');
OT_14 = importdata('Uttak_2014.txt');
OT_15 = importdata('Uttak_2015.txt');
OT_16 = importdata('Uttak_2016.txt');
OT_17 = importdata('Uttak_2017.txt');
OT_18 = importdata('Uttak_2018.txt');
OT_19 = importdata('Uttak_2019.txt');

% Put all total outtake data in a 24x132 matrix. Converting with WFE for live fish weight
OT_all = [OT_09, OT_10, OT_11, OT_12, OT_13, ...
          OT_14, OT_15, OT_16, OT_17, OT_18, OT_19];

%%%%CALCULATION OF TRANSPORT VOLUME USED%%%%
% Establishing Density matrix for volume calculation.
% Using RSPCA welfare standards for transport density.

D_mat = zeros(size(AW_all));

for k = 1:24
    for j = 1:132
        if AW_all(k,j) ≥ 5
            D_mat(k,j) = 1/125;
```

```
        elseif AW_all(k,j) < 5 && AW_all(k,j) ≥ 4
            D_mat(k,j) = 1/110;
        elseif AW_all(k,j) < 4 && AW_all(k,j) ≥ 3.5
            D_mat(k,j) = 1/100;
        elseif AW_all(k,j) < 3.5 && AW_all(k,j) ≥ 3
            D_mat(k,j) = 1/90;
        elseif AW_all(k,j) < 3 && AW_all(k,j) ≥ 2
            D_mat(k,j) = 1/75;
        elseif AW_all(k,j) < 2 && AW_all(k,j) ≥ 1
            D_mat(k,j) = 1/60;
        elseif AW_all(k,j) < 1 && AW_all(k,j) ≥ 0.001
            D_mat(k,j) = 1/45;
        end
    end
end


% Multiply req. density for each average salmon weight with
% the production volume (tonnes) to obtain transport volume needed.
Vol_LFC = D_mat.*OT_all*1000; %[m3/kg]*[tonne]*[kg/tonne]
SUM_LFC = sum(Vol_LFC);

% Volume needed if stocking density is set to 150 kg/m3
Vol_180 = (1/180)*OT_all*1000; %[m3/kg]*[tonne]*[kg/tonne]
SUM_180 = sum(Vol_180);

% Transport volume needed using SBV. Stocking density set to 600 kg/m3
SBV_f = 1/600;
Vol_SBV = SBV_f*OT_all*1000; %[m3/kg]*[tonne]*[kg/tonne]
SUM_SBV = sum(Vol_SBV);

% Total LWE salmon taken out
LWE = sum(OT_all);
LWE = sum(OT_all);
```

Appendix C: Salmon loss distribution 2009-2019

Table C1.1: Lost individual salmon [1000 pc.], on county basis in 2009. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
>1 yr cohort	**A**	18	9	11	6	3	4	4	3	3	2	5	4
	B	52	49	18	11	11	27	7	4	2	1	0	0
	C	36	26	16	13	8	5	6	1	0	0	0	0
	D	52	41	89	62	32	16	5	16	0	0	0	2
	E	63	58	45	65	35	6	1	1	1	2	0	0
	F	16	9	11	13	11	6	2	0	0	0	0	0
	G	76	66	33	22	16	6	1	0	0	0	0	0
	H	34	39	49	54	34	25	11	0	0	3	3	5
1 yr cohort	**A**	176	102	90	118	80	93	74	55	39	46	26	27
	B	365	173	157	160	205	184	142	151	66	58	47	34
	C	267	174	139	171	153	166	107	159	112	123	52	33
	D	247	169	126	151	116	145	132	142	133	83	61	56
	E	206	177	162	202	155	169	139	190	117	77	55	48
	F	95	69	69	46	71	41	202	225	90	111	25	20
	G	200	147	117	104	104	384	819	520	280	216	114	116
	H	109	64	80	91	53	104	131	86	104	45	40	156
0 yr cohort	**A**	0	0	0	0	117	161	253	395	267	431	89	67
	B	0	12	8	40	130	208	347	259	192	144	175	138
	C	0	218	160	156	311	241	624	348	374	805	953	300
	D	0	1	140	245	228	344	732	466	587	732	446	457
	E	0	0	5	49	194	446	302	279	206	206	1686	178
	F	0	0	0	8	53	269	72	47	108	316	396	288
	G	0	0	0	104	306	807	430	298	361	597	519	521
	H	0	0	0	31	111	326	358	256	297	243	208	260

Table C1.2: Lost individual salmon [1000 pc.], on county basis in 2010. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
>1 yr cohort	**A**	20	30	47	23	15	33	13	8	17	5	7	6
	B	35	41	37	43	53	13	8	6	6	3	1	0
	C	35	40	43	24	14	10	1	0	0	0	0	0
	D	57	56	62	60	38	25	4	0	0	1	0	0
	E	41	35	40	47	40	14	7	7	1	5	0	0
	F	24	23	17	15	11	5	1	1	0	0	0	0
	G	72	40	41	24	18	14	3	1	0	0	0	0
	H	55	46	46	40	36	33	5	0	0	4	4	3
1 yr cohort	**A**	60	69	104	85	76	64	73	82	101	72	37	48
	B	176	171	189	124	153	158	850	102	64	40	34	24
	C	208	129	191	243	160	85	165	94	81	60	41	33
	D	179	159	191	380	289	201	239	122	151	139	115	92
	E	170	141	187	211	206	244	221	170	134	116	64	112
	F	185	107	78	67	50	99	152	223	101	51	51	51
	G	279	205	224	167	156	435	933	580	296	138	71	78
	H	118	119	476	189	100	225	825	184	80	52	41	48
0 yr cohort	**A**	0	0	0	467	436	222	294	331	295	250	155	135
	B	0	0	0	223	462	266	500	694	417	311	128	135
	C	0	220	286	556	337	223	689	403	321	321	615	277
	D	0	5	165	180	620	421	1031	490	720	663	352	451
	E	0	0	28	125	215	183	642	115	235	654	353	377
	F	0	0	0	19	108	97	124	162	201	132	144	154
	G	0	0	6	108	243	414	509	259	469	356	259	190
	H	0	8	289	40	136	119	618	332	383	533	406	520

Table C1.3: Lost individual salmon [1000 pc.], on county basis in 2011. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
>1 yr cohort	A	34	53	37	20	16	13	7	4	14	18	25	2
	B	36	43	43	23	10	33	6	3	3	1	0	0
	C	33	39	61	38	39	11	4	1	0	0	0	0
	D	78	93	93	69	150	39	20	4	0	0	0	0
	E	95	108	96	61	34	29	12	6	2	1	0	0
	F	32	35	18	22	15	11	0	0	0	0	0	0
	G	87	47	43	60	24	42	14	1	0	0	0	0
	H	44	36	41	49	28	20	6	1	0	0	0	0
1 yr cohort	A	144	175	265	230	117	115	170	71	60	51	34	28
	B	159	160	213	195	106	164	116	62	125	65	39	45
	C	279	245	292	263	202	143	242	105	102	122	119	92
	D	496	337	369	339	130	167	248	134	254	258	190	117
	E	343	323	286	374	240	368	250	161	442	308	120	68
	F	142	127	112	90	57	249	172	130	224	175	107	87
	G	217	276	372	194	157	339	382	681	418	189	121	157
	H	284	169	162	214	175	679	346	367	158	117	58	58
0 yr cohort	A	0	0	0	28	260	658	742	496	440	520	183	145
	B	0	1	0	177	290	523	300	393	509	384	220	151
	C	0	0	86	101	462	333	581	437	632	266	298	230
	D	0	63	190	126	419	939	1283	1136	1004	586	318	286
	E	0	0	22	134	52	135	225	246	247	132	90	249
	F	0	0	0	2	135	67	173	134	165	139	160	140
	G	6	8	0	121	205	247	315	293	303	288	368	307
	H	0	0	0	33	54	106	94	235	233	159	199	120

Table C1.4: Lost individual salmon [1000 pc.], on county basis in 2012. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
>1 yr cohort	A	33	34	33	22	21	6	14	8	8	2	1	1
	B	33	36	42	33	25	17	9	5	5	6	1	0
	C	60	101	83	81	95	39	7	3	0	0	0	0
	D	69	59	60	44	35	21	1	0	3	1	0	0
	E	69	49	64	61	33	11	5	5	1	0	0	0
	F	90	43	45	23	21	2	0	0	0	0	0	0
	G	81	47	30	42	26	10	7	0	0	0	0	0
	H	68	77	74	44	38	20	6	0	0	1	4	0
1 yr cohort	A	182	149	130	108	116	123	115	60	171	64	178	91
	B	130	148	166	107	105	90	69	59	54	58	69	106
	C	211	142	229	363	185	169	112	119	171	104	106	94
	D	358	176	181	225	342	371	221	247	283	173	96	83
	E	573	73	49	90	55	74	112	67	62	45	67	58
	F	118	102	104	94	88	99	118	97	67	77	63	40
	G	244	189	310	213	309	553	478	563	489	170	178	97
	H	114	126	133	88	167	200	207	303	245	111	71	82
0 yr cohort	A	0	0	0	8	405	494	237	162	403	183	133	105
	B	0	0	0	189	365	277	246	407	252	178	136	379
	C	15	40	70	89	567	189	243	289	411	297	201	179
	D	0	186	185	256	272	462	400	453	389	452	281	177
	E	0	0	65	111	382	116	278	201	241	258	188	143
	F	0	0	0	10	57	57	107	237	136	173	209	148
	G	0	0	1	86	156	530	276	360	346	280	557	340
	H	0	0	16	89	82	167	139	246	114	126	99	95

Table C1.5: Lost individual salmon [1000 pc.], on county basis in 2013. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
>1 yr cohort	**A**	103	72	44	34	18	10	5	10	9	2	0	0
	B	38	52	48	43	35	16	5	4	5	1	1	0
	C	147	89	22	17	14	6	3	2	1	12	2	1
	D	107	54	45	43	32	7	3	0	2	1	0	0
	E	34	27	18	16	21	9	1	0	0	0	0	0
	F	35	48	25	19	10	1	0	0	0	0	0	0
	G	107	81	55	46	43	28	5	5	2	0	0	3
	H	108	135	150	138	138	62	12	0	1	4	1	2
1 yr cohort	**A**	142	136	178	144	136	134	163	210	134	84	67	73
	B	112	143	142	147	139	114	55	52	81	84	32	35
	C	239	191	259	238	241	138	182	189	266	299	127	82
	D	184	98	109	114	144	153	231	224	310	345	269	78
	E	144	132	142	152	85	189	129	121	155	240	101	98
	F	126	129	117	83	42	49	48	79	111	82	45	25
	G	246	108	161	125	156	339	460	351	547	223	163	94
	H	129	124	126	113	56	228	421	368	251	109	113	72
0 yr cohort	**A**	0	0	0	0	29	225	309	123	232	200	173	132
	B	0	0	0	194	254	135	233	340	219	342	160	207
	C	13	72	111	217	851	241	111	152	349	298	186	215
	D	1	160	447	667	429	244	263	460	753	379	236	205
	E	1	1	1	11	63	63	32	42	42	45	56	51
	F	0	0	4	21	68	19	40	29	49	86	155	99
	G	0	0	1	165	174	51	140	161	292	938	1434	814
	H	0	0	0	80	15	41	65	72	117	252	97	119

Table C1.6: Lost individual salmon [1000 pc.], on county basis in 2014. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
>1 yr cohort	**A**	65	80	62	33	18	14	12	6	2	1	0	0
	B	44	28	35	104	29	23	8	5	0	0	0	0
	C	108	76	191	48	15	12	2	1	0	0	3	0
	D	127	144	72	65	60	27	0	0	0	2	0	0
	E	89	79	75	78	48	25	1	1	0	0	0	0
	F	35	24	30	9	5	2	0	0	0	0	0	0
	G	136	69	54	49	52	25	2	1	1	0	0	0
	H	92	45	55	66	52	21	2	1	0	5	1	2
1 yr cohort	**A**	142	152	158	115	100	112	373	135	97	98	80	44
	B	313	225	199	145	131	166	98	76	104	72	31	37
	C	179	164	193	152	272	250	215	143	165	279	79	57
	D	256	235	414	436	273	251	309	411	330	392	250	116
	E	40	83	132	102	40	64	78	320	222	120	52	33
	F	104	80	96	73	49	165	74	144	150	241	46	42
	G	500	480	646	421	540	781	619	548	527	523	162	123
	H	112	111	109	109	387	422	642	403	263	176	149	113
0 yr cohort	**A**	0	0	1	107	249	140	219	209	447	208	265	186
	B	0	0	0	112	359	291	133	211	172	238	177	178
	C	12	7	11	45	264	220	139	284	474	275	194	229
	D	0	0	24	102	177	120	89	438	398	184	114	127
	E	0	0	57	95	125	108	161	360	697	362	409	308
	F	0	0	67	52	40	30	63	95	1054	501	291	115
	G	0	0	7	68	88	53	135	341	1118	1213	447	388
	H	0	0	1	20	12	138	105	194	225	292	220	138

Table C1.7: Lost individual salmon [1000 pc.], on county basis in 2015. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
>1 yr cohort	**A**	49	50	30	17	7	6	4	3	0	0	0	0
	B	68	111	48	28	25	23	5	2	0	0	0	0
	C	34	33	50	16	12	3	1	1	0	4	0	0
	D	114	102	96	64	40	16	2	0	1	0	0	0
	E	39	24	19	13	7	3	1	1	2	0	1	2
	F	33	38	27	16	8	0	0	0	0	0	0	0
	G	121	75	77	49	28	35	1	0	0	0	0	0
	H	73	88	92	96	73	36	5	0	1	1	1	0
1 yr cohort	**A**	142	148	160	125	104	106	55	69	63	105	79	53
	B	346	306	385	206	157	181	109	96	93	116	89	88
	C	338	336	310	285	1376	842	457	162	357	188	162	164
	D	179	167	168	127	110	131	117	374	359	444	320	169
	E	286	201	270	160	237	344	320	506	785	468	170	84
	F	142	110	177	166	117	269	201	202	230	164	117	61
	G	221	251	479	392	500	459	682	424	570	308	287	128
	H	112	117	174	159	176	342	362	357	456	292	229	146
0 yr cohort	**A**	0	140	89	23	130	164	191	129	999	177	144	271
	B	0	0	0	76	345	110	105	184	160	210	396	273
	C	11	30	30	21	251	201	307	183	174	180	234	235
	D	0	7	128	230	191	149	296	543	719	570	490	327
	E	0	0	2	30	76	14	56	120	107	95	77	56
	F	0	0	6	7	21	20	35	41	89	200	155	187
	G	3	0	1	163	185	142	152	417	461	341	442	264
	H	0	0	4	8	15	28	104	82	88	115	91	95

Table C1.8: Lost individual salmon [1000 pc.], on county basis in 2016. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
>1 yr cohort	**A**	52	38	34	22	9	5	4	6	3	1	0	0
	B	80	121	73	32	16	7	4	1	1	0	0	0
	C	100	55	50	41	38	11	1	3	2	3	1	1
	D	146	133	204	55	17	2	0	1	1	1	0	0
	E	83	121	67	12	4	0	0	0	0	0	0	0
	F	113	45	33	10	2	0	0	0	0	0	0	0
	G	116	173	126	68	20	5	0	0	0	0	0	0
	H	158	119	95	87	45	8	0	0	0	0	0	0
1 yr cohort	**A**	271	237	301	266	197	156	186	221	126	126	110	83
	B	234	368	313	169	151	212	234	125	319	89	92	118
	C	209	206	184	190	294	423	848	216	238	341	121	124
	D	343	465	400	607	679	648	613	722	1797	642	441	426
	E	109	139	148	196	167	215	271	219	190	45	40	26
	F	201	271	258	266	145	197	228	122	179	170	196	79
	G	789	386	515	618	506	730	651	433	455	255	177	166
	H	207	267	166	171	254	451	245	565	318	201	219	142
0 yr cohort	**A**	0	0	0	8	133	247	113	153	218	181	106	121
	B	41	58	22	69	259	104	149	186	209	210	167	167
	C	27	75	65	165	402	234	160	164	206	219	170	166
	D	0	0	4	129	192	148	171	227	243	243	82	63
	E	0	4	129	416	180	85	142	224	479	388	436	447
	F	0	0	6	76	75	27	62	79	129	144	151	142
	G	7	60	164	102	113	63	155	182	400	499	438	376
	H	0	0	2	14	22	9	163	298	201	387	290	140

Table C1.9: Lost individual salmon [1000 pc.], on county basis in 2017. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
>1 yr cohort	**A**	70	81	67	46	28	23	13	13	18	1	0	0
	B	86	71	78	66	60	28	8	2	1	0	0	0
	C	54	36	28	22	28	13	5	7	1	1	1	0
	D	455	285	310	134	23	2	1	1	0	1	1	1
	E	30	20	15	12	9	7	7	0	0	0	0	0
	F	71	62	50	42	20	0	0	0	0	2	0	0
	G	188	136	126	39	18	9	1	2	6	1	0	1
	H	174	97	97	70	39	2	5	0	0	0	0	0
1 yr cohort	**A**	127	143	182	139	96	96	131	80	164	130	104	88
	B	219	150	156	109	133	116	140	110	154	136	121	106
	C	233	228	175	183	220	204	314	364	287	260	213	169
	D	154	160	91	157	273	270	287	530	537	492	334	294
	E	478	361	433	494	690	416	614	676	590	409	174	150
	F	179	239	162	165	400	496	395	330	337	166	182	240
	G	369	338	527	539	809	739	1038	982	1497	527	240	240
	H	183	248	243	177	213	211	324	414	385	250	247	187
0 yr cohort	**A**	32	37	34	40	153	203	61	65	90	103	103	132
	B	3	12	2	209	331	87	101	146	232	224	318	238
	C	25	18	44	55	309	129	163	170	220	200	309	463
	D	0	1	212	330	311	125	151	398	354	395	373	396
	E	0	0	4	92	59	23	24	35	101	260	228	246
	F	0	0	8	119	47	81	85	49	114	503	278	250
	G	0	0	45	143	141	95	72	184	229	539	666	540
	H	0	0	6	12	4	7	58	81	98	154	81	102

Table C1.10: Lost individual salmon [1000 pc.], on county basis in 2018. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
>1 yr cohort	**A**	75	63	46	27	17	7	4	2	0	12	0	0
	B	107	54	49	45	20	12	1	0	0	0	0	0
	C	147	93	87	62	34	32	32	3	1	0	0	0
	D	202	144	104	39	21	8	2	0	0	0	0	0
	E	138	68	28	12	12	3	1	1	0	0	0	0
	F	118	58	32	16	6	0	0	0	0	0	0	0
	G	233	113	79	30	5	1	0	0	0	0	0	0
	H	167	161	132	164	60	15	0	0	0	1	0	0
1 yr cohort	**A**	243	206	199	187	127	152	82	112	138	122	84	62
	B	368	269	309	356	223	122	131	125	192	241	130	61
	C	667	476	405	428	414	259	323	360	237	198	112	74
	D	503	356	289	303	301	270	743	740	637	436	326	362
	E	137	65	65	69	77	151	103	79	101	59	54	22
	F	465	261	258	252	300	415	597	363	358	176	120	159
	G	953	427	561	557	668	855	778	520	351	270	161	257
	H	99	150	133	210	228	428	183	250	382	248	263	349
0 yr cohort	**A**	52	124	89	128	185	193	84	191	114	119	84	101
	B	3	18	159	515	176	152	118	205	180	175	158	257
	C	183	106	131	182	327	128	83	164	236	402	384	427
	D	0	0	83	206	298	79	89	108	172	189	191	181
	E	0	4	337	1254	112	97	80	133	323	145	1236	228
	F	0	0	19	260	54	23	27	53	121	140	175	194
	G	0	1	126	434	128	71	284	320	191	203	395	403
	H	0	0	2	75	16	5	34	65	80	62	134	65

Table C1.11: Lost individual salmon [1000 pc.], on county basis in 2019. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
>1 yr cohort	**A**	57	89	91	67	49	33	15	5	1	0	0	0
	B	50	62	54	47	45	14	5	4	0	0	0	0
	C	66	77	65	66	157	21	35	5	5	0	0	2
	D	281	115	102	54	55	2	1	1	0	1	1	0
	E	23	8	21	8	42	2	1	1	0	0	0	0
	F	102	80	41	39	4	1	0	0	0	0	0	0
	G	228	217	215	92	31	10	4	0	0	0	0	0
	H	219	146	147	103	42	19	0	0	0	0	0	0
1 yr cohort	**A**	188	206	212	129	98	97	82	61	174	145	124	200
	B	294	236	300	289	4150	261	198	219	241	152	166	143
	C	655	571	475	577	3751	322	196	233	251	308	405	333
	D	277	176	131	209	194	156	294	285	295	198	167	158
	E	289	444	315	330	216	310	334	372	492	249	138	124
	F	199	214	163	185	313	487	310	227	148	279	257	192
	G	709	514	496	653	614	709	831	752	501	361	375	391
	H	90	142	192	164	151	114	198	230	560	415	236	117
0 yr cohort	**A**	0	0	0	14	464	177	57	196	94	115	124	192
	B	0	0	27	58	718	101	50	106	171	220	248	291
	C	104	35	20	34	881	604	104	158	209	355	317	286
	D	8	36	83	166	233	86	162	331	396	330	405	355
	E	0	0	0	24	14	21	40	55	57	50	61	113
	F	1	0	7	45	27	17	45	93	150	364	127	362
	G	0	9	54	175	92	59	111	193	305	410	616	567
	H	0	0	2	32	22	23	31	99	159	93	239	234

Table C2.1: Average weight of reported salmon in inventory [kg], on county basis in 2009. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
>1 yr cohort	**A**	4.17	4.04	3.97	3.70	3.79	3.49	3.91	4.40	5.12	5.70	5.88	5.63
	B	3.72	3.83	3.74	3.69	3.66	3.80	4.27	4.97	5.50	5.63	6.55	6.55
	C	3.95	3.99	3.85	3.97	4.05	4.26	4.47	4.88	7.86	8.50	0.00	0.00
	D	4.00	4.15	4.27	4.60	4.89	5.03	5.78	13.96	2.81	14.83	0.00	3.65
	E	3.76	3.92	4.12	4.11	4.32	3.83	3.97	4.39	2.26	4.46	4.38	0.00
	F	3.61	3.85	4.03	4.34	4.47	4.83	0.00	0.00	0.00	0.00	0.00	0.00
	G	3.91	3.85	4.15	4.37	4.82	5.30	5.25	13.96	13.96	0.00	0.00	0.00
	H	3.63	3.79	4.17	4.41	4.83	5.08	4.85	3.32	8.65	8.46	10.12	10.39
1 yr cohort	**A**	0.80	0.88	0.98	1.07	1.17	1.33	1.69	2.23	2.71	3.18	3.53	3.78
	B	0.91	1.00	1.09	1.20	1.36	1.58	2.02	2.47	2.87	3.27	3.46	3.55
	C	1.04	1.17	1.23	1.35	1.60	1.89	2.43	2.96	3.42	3.76	3.92	4.17
	D	1.04	1.17	1.31	1.53	1.77	2.18	2.63	3.10	3.49	3.86	4.17	4.42
	E	1.07	1.17	1.31	1.47	1.71	2.10	2.51	2.85	3.19	3.52	3.75	3.85
	F	1.12	1.24	1.44	1.55	1.73	2.14	2.48	2.80	3.18	3.45	3.67	3.93
	G	1.28	1.42	1.54	1.70	1.95	2.29	2.62	2.85	3.12	3.42	3.69	3.83
	H	0.97	1.03	1.16	1.35	1.60	1.93	2.24	2.58	2.97	3.37	3.65	3.88
0 yr cohort	**A**	0.00	0.00	0.00	0.00	0.09	0.12	0.21	0.32	0.47	0.67	0.84	0.89
	B	0.12	0.13	0.15	0.10	0.10	0.13	0.21	0.33	0.45	0.57	0.77	0.95
	C	0.00	0.21	0.22	0.22	0.17	0.20	0.30	0.46	0.59	0.75	0.90	1.11
	D	0.00	0.08	0.39	0.191	0.168	0.176	0.278	0.392	0.453	0.599	0.752	0.898
	E	0.00	0.00	0.14	0.13	0.14	0.19	0.27	0.40	0.56	0.70	0.85	1.01
	F	0.00	0.00	0.00	0.12	0.14	0.26	0.37	0.64	0.76	0.82	0.94	1.13
	G	0.27	0.27	0.15	0.16	0.19	0.29	0.49	0.72	0.80	0.81	1.00	1.12
	H	0.00	0.06	0.05	0.12	0.14	0.20	0.32	0.42	0.47	0.51	0.69	0.84

Table C2.2: Average weight of reported salmon in inventory [kg], on county basis in 2010. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
>1 yr cohort	**A**	3.91	3.87	3.74	3.60	3.64	3.87	4.36	4.89	5.54	6.18	6.59	6.94
	B	3.53	3.49	3.48	3.46	3.57	3.85	4.46	4.81	5.22	5.00	5.42	6.16
	C	4.32	4.38	4.35	4.54	4.81	5.22	6.02	4.79	7.19	5.24	5.52	5.74
	D	4.57	4.63	4.72	4.81	5.34	5.82	5.97	11.98	11.93	0.00	0.00	0.00
	E	4.05	4.29	4.42	4.61	4.76	5.00	4.81	5.83	11.49	0.30	13.37	0.00
	F	4.13	4.40	4.50	4.69	4.91	5.24	4.71	4.41	0.00	0.00	0.00	0.00
	G	4.18	4.37	4.60	4.85	4.89	4.60	7.40	12.98	12.80	12.50	0.00	0.00
	H	4.05	4.19	4.36	4.70	5.07	5.01	8.95	8.91	8.89	8.97	8.91	8.91
1 yr cohort	**A**	0.93	1.03	1.10	1.18	1.28	1.58	2.00	2.60	3.16	3.66	3.94	4.14
	B	1.05	1.16	1.27	1.41	1.56	1.86	2.30	2.70	3.26	3.59	3.77	3.93
	C	1.17	1.34	1.47	1.63	1.84	2.16	2.65	3.19	3.60	3.99	4.27	4.38
	D	1.03	1.14	1.28	1.41	1.61	1.93	2.37	2.90	3.26	3.59	3.79	3.96
	E	1.10	1.23	1.38	1.58	1.86	2.20	2.70	3.19	3.58	3.36	4.08	4.27
	F	1.27	1.36	1.55	1.73	1.95	2.21	2.56	2.87	3.20	3.43	3.66	3.90
	G	1.28	1.40	1.53	1.69	1.94	2.15	2.46	2.71	3.00	3.37	3.69	3.90
	H	0.95	1.02	1.16	1.36	1.58	1.99	2.19	2.50	2.87	3.30	3.65	4.00
0 yr cohort	**A**	0.00	0.00	0.00	0.09	0.09	0.11	0.17	0.24	0.36	0.48	0.57	0.68
	B	0.00	0.00	0.00	0.11	0.31	0.16	0.22	0.29	0.41	0.52	0.67	0.79
	C	0.00	0.21	0.15	0.19	0.16	0.19	0.27	0.43	0.49	0.61	0.76	0.90
	D	0.00	0.08	0.09	0.125	0.124	0.165	0.249	0.339	0.465	0.609	0.740	0.878
	E	0.00	0.00	0.14	0.13	0.15	0.18	0.27	0.43	0.63	0.60	0.79	0.92
	F	0.00	0.00	0.00	0.12	0.15	0.20	0.35	0.61	0.79	0.81	0.83	0.98
	G	0.00	0.00	0.20	0.15	0.16	0.25	0.43	0.64	0.69	0.79	0.88	1.03
	H	0.04	0.11	0.15	0.13	0.13	0.18	0.28	0.43	0.40	0.42	0.56	0.76

Table C2.3: Average weight of reported salmon in inventory [kg], on county basis in 2011. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
>1 yr cohort	**A**	4.32	4.27	4.28	4.19	4.08	4.25	4.72	5.28	5.76	6.38	6.59	7.08
	B	3.95	4.01	3.94	3.97	4.07	4.33	4.43	4.77	4.74	4.76	0.00	0.00
	C	4.46	4.53	4.51	4.71	4.81	4.86	5.19	6.10	6.35	10.16	5.43	0.00
	D	4.15	4.29	4.52	4.81	5.07	5.35	5.90	12.28	11.90	0.00	0.00	0.00
	E	4.42	4.63	4.64	4.73	5.19	5.41	5.59	6.82	6.25	11.36	10.24	12.28
	F	4.15	4.52	4.73	4.90	5.15	6.00	0.00	0.00	0.00	4.41	0.00	0.00
	G	4.16	4.42	4.57	4.24	5.03	5.05	4.29	2.39	11.50	11.50	11.50	0.00
	H	4.13	4.18	4.61	4.85	5.45	6.16	7.70	0.00	0.00	0.00	0.00	0.00
1 yr cohort	**A**	0.78	0.85	0.93	1.01	1.11	1.28	1.64	2.18	2.72	3.14	3.55	3.84
	B	0.89	0.93	1.07	1.18	1.34	1.56	1.99	2.56	3.04	3.39	3.62	3.76
	C	0.99	1.08	1.17	1.28	1.48	1.74	2.25	2.79	3.19	3.48	3.60	3.92
	D	0.97	1.07	1.27	1.40	1.63	1.93	2.44	2.94	3.35	3.66	3.91	4.04
	E	1.05	1.16	1.31	1.48	1.73	2.11	2.58	3.04	3.44	3.47	3.60	3.76
	F	1.10	1.20	1.33	1.49	1.66	1.92	2.25	2.63	3.03	3.22	3.56	3.67
	G	1.14	1.25	1.40	1.61	1.85	2.09	2.37	2.68	3.02	3.33	3.54	3.75
	H	0.71	0.82	0.95	1.06	1.25	1.62	1.97	2.36	2.61	2.99	3.25	3.53
0 yr cohort	**A**	0.00	0.00	0.00	0.11	0.09	0.11	0.16	0.24	0.36	0.50	0.64	0.77
	B	0.00	2.13	0.00	0.07	0.08	0.11	0.17	0.26	0.38	0.47	0.66	0.78
	C	0.00	0.00	0.06	0.12	0.11	0.14	0.23	0.35	0.45	0.59	0.78	0.93
	D	0.00	0.11	0.12	0.126	0.145	0.176	0.266	0.367	0.472	0.623	0.808	0.979
	E	0.00	0.00	0.09	0.11	0.11	0.17	0.27	0.41	0.57	0.68	0.86	1.12
	F	0.00	0.00	0.00	0.12	0.11	0.15	0.25	0.44	0.57	0.59	0.71	0.87
	G	0.00	0.00	0.00	0.12	0.13	0.21	0.36	0.55	0.65	0.79	0.99	1.20
	H	0.00	0.00	0.00	0.48	0.11	0.16	0.26	0.35	0.37	0.43	0.52	0.67

Table C2.4: Average weight of reported salmon in inventory [kg], on county basis in 2012. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
>1 yr cohort	**A**	4.18	4.14	4.02	3.96	4.07	3.77	4.45	4.75	4.86	5.03	5.05	5.32
	B	3.87	3.92	4.00	4.08	4.01	4.06	4.70	4.96	4.93	4.42	0.00	0.00
	C	3.97	4.03	4.09	4.14	4.30	4.52	4.61	4.55	14.24	0.00	0.00	0.00
	D	4.35	4.63	4.82	5.16	5.29	5.36	13.43	13.43	5.82	13.36	13.36	0.00
	E	3.89	4.19	4.43	4.69	4.85	4.52	4.39	5.80	5.91	11.87	11.86	0.00
	F	3.92	4.12	4.70	4.94	5.01	4.51	0.00	0.00	0.00	0.00	0.00	0.00
	G	3.87	3.95	4.20	4.70	5.10	5.64	13.20	13.41	13.53	12.59	12.59	0.00
	H	3.85	4.11	4.32	4.58	4.66	4.94	4.98	8.93	8.93	9.97	9.98	9.98
1 yr cohort	**A**	0.90	0.99	1.10	1.18	1.29	1.48	1.83	2.36	2.92	3.35	3.61	3.84
	B	0.91	1.08	1.20	1.33	1.50	1.80	2.24	2.60	3.12	3.54	3.72	3.81
	C	1.06	1.20	1.35	1.48	1.72	2.02	2.51	2.96	3.39	3.71	4.00	4.06
	D	1.13	1.29	1.49	1.71	1.94	2.28	2.73	3.27	3.61	3.97	4.34	4.69
	E	1.31	1.50	1.65	1.99	2.28	2.63	3.01	3.44	3.88	4.37	4.57	4.86
	F	1.02	1.15	1.32	1.49	1.68	1.96	2.31	2.73	3.15	3.43	3.74	4.04
	G	1.36	1.51	1.68	1.90	2.15	2.43	2.67	2.97	3.37	3.73	3.88	3.98
	H	0.81	0.92	1.08	1.24	1.37	1.60	1.99	2.37	2.81	3.17	3.56	3.89
0 yr cohort	**A**	0.00	0.00	0.00	0.12	0.12	0.17	0.23	0.33	0.48	0.64	0.92	1.01
	B	0.00	0.00	0.00	0.12	0.12	0.15	0.22	0.34	0.40	0.53	0.68	0.80
	C	0.27	0.27	0.23	0.17	0.16	0.20	0.30	0.45	0.59	0.72	0.92	1.10
	D	0.00	0.00	0.18	0.154	0.167	0.218	0.313	0.438	0.531	0.687	0.860	1.026
	E	0.00	0.00	0.13	0.15	0.19	0.24	0.35	0.57	0.74	0.85	1.01	1.18
	F	0.00	0.00	0.00	0.14	0.15	0.22	0.36	0.52	0.62	0.77	0.92	1.07
	G	0.00	0.00	0.18	0.15	0.20	0.31	0.49	0.63	0.69	0.81	0.96	1.16
	H	0.06	0.00	0.17	0.16	0.18	0.24	0.30	0.36	0.43	0.51	0.65	0.80

Table C2.5: Average weight of reported salmon in inventory [kg], on county basis in 2013. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
>1 yr cohort	**A**	4.07	4.16	4.21	4.25	4.23	4.29	4.89	5.17	5.62	7.19	0.00	0.00
	B	3.86	3.83	3.99	3.96	4.07	4.28	4.65	5.11	6.18	6.75	7.13	0.00
	C	4.46	4.44	4.58	4.55	4.69	4.29	3.45	3.36	3.47	3.90	3.74	4.66
	D	5.00	5.19	5.39	5.66	6.01	7.53	15.13	15.19	4.47	15.31	0.00	0.00
	E	5.25	5.55	5.61	5.95	6.56	7.28	12.71	16.06	15.41	15.35	0.00	0.00
	F	4.39	4.54	4.67	4.73	5.01	3.58	4.08	3.69	3.96	2.69	0.00	0.00
	G	4.08	4.23	4.55	4.77	4.92	4.89	3.86	4.41	4.86	6.03	6.27	1.69
	H	4.13	4.26	4.42	4.71	5.13	5.11	8.85	8.84	2.49	8.67	8.64	8.63
1 yr cohort	**A**	1.07	1.12	1.23	1.33	1.46	1.68	2.06	2.59	3.16	3.61	4.02	4.25
	B	0.92	1.01	1.11	1.24	1.35	1.62	2.09	2.61	2.94	3.28	3.50	3.66
	C	1.26	1.38	1.51	1.61	1.81	2.13	2.63	3.04	3.42	3.72	3.91	4.10
	D	1.16	1.28	1.41	1.56	1.83	2.23	2.61	3.00	3.16	3.48	3.75	4.12
	E	1.33	1.47	1.60	1.77	1.95	2.27	2.56	2.94	3.22	3.45	3.65	3.79
	F	1.23	1.34	1.45	1.60	1.82	2.17	2.58	2.92	3.30	3.54	3.78	4.04
	G	1.30	1.40	1.52	1.66	1.89	2.09	2.23	2.57	2.86	3.15	3.26	3.78
	H	0.91	0.99	1.11	1.27	1.49	1.80	2.08	2.46	2.84	3.39	3.74	4.04
0 yr cohort	**A**	0.00	0.00	0.00	0.00	0.15	0.15	0.22	0.35	0.54	0.76	0.95	1.08
	B	0.00	0.00	0.00	0.11	0.11	0.14	0.23	0.35	0.49	0.59	0.74	0.89
	C	0.15	0.19	0.22	0.16	0.15	0.17	0.29	0.46	0.60	0.75	0.95	1.12
	D	0.15	0.21	0.16	0.149	0.171	0.224	0.341	0.476	0.607	0.759	0.932	1.114
	E	1.67	1.77	1.87	1.50	0.10	0.14	0.23	0.40	0.56	0.79	1.04	1.27
	F	0.00	0.00	0.26	0.14	0.13	0.23	0.37	0.57	0.75	0.77	0.90	1.09
	G	0.73	0.89	0.36	0.19	0.21	0.30	0.48	0.70	0.79	0.90	1.07	1.28
	H	0.00	0.00	0.16	0.17	0.22	0.27	0.41	0.39	0.41	0.46	0.60	0.74

Table C2.6: Average weight of reported salmon in inventory [kg], on county basis in 2014. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
>1 yr cohort	**A**	4.51	4.53	4.51	4.49	4.64	4.71	5.35	5.52	4.59	5.66	0.00	0.00
	B	3.78	3.88	3.99	4.26	4.64	4.80	5.36	5.56	0.00	0.00	0.00	0.00
	C	4.41	4.76	4.90	4.95	5.00	5.53	6.37	17.82	17.82	17.82	0.00	0.00
	D	4.56	4.84	5.16	5.66	6.14	13.74	13.00	12.74	12.58	11.58	0.00	0.00
	E	4.02	4.32	4.67	5.03	5.39	5.57	9.44	8.93	8.65	7.95	8.75	3.60
	F	4.40	4.81	5.07	5.16	4.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	G	4.11	4.35	4.61	5.09	5.42	4.92	8.14	13.83	13.55	12.91	10.05	8.58
	H	4.28	4.48	4.64	4.93	5.41	5.66	8.07	7.88	0.12	7.98	7.90	7.64
1 yr cohort	**A**	1.25	1.37	1.53	1.67	1.85	2.07	2.48	3.07	3.57	3.95	4.16	4.33
	B	1.02	1.13	1.25	1.39	1.56	1.80	2.28	2.66	3.08	3.46	3.74	3.81
	C	1.26	1.39	1.56	1.71	1.96	2.19	2.58	2.99	3.38	3.67	3.90	4.20
	D	1.28	1.45	1.61	1.82	2.10	2.43	2.77	3.16	3.51	3.76	4.11	4.51
	E	1.48	1.69	1.88	2.12	2.43	2.79	3.10	3.43	3.72	4.21	4.62	4.85
	F	1.25	1.43	1.61	1.81	2.03	2.20	2.49	2.82	3.18	3.53	3.92	4.30
	G	1.46	1.62	1.77	1.98	2.20	2.46	2.63	2.89	3.15	3.45	3.80	4.10
	H	0.88	1.01	1.09	1.23	1.46	1.73	2.06	2.46	2.96	3.38	3.78	4.10
0 yr cohort	**A**	0.00	0.00	0.31	0.26	0.15	0.17	0.23	0.33	0.49	0.68	0.80	0.94
	B	0.00	0.00	0.28	0.11	0.11	0.15	0.23	0.32	0.45	0.56	0.73	0.86
	C	0.20	0.26	0.31	0.19	0.15	0.20	0.30	0.41	0.56	0.70	0.89	1.04
	D	0.00	0.00	0.17	0.177	0.188	0.262	0.399	0.547	0.658	0.835	1.033	1.251
	E	0.00	0.22	0.17	0.17	0.20	0.27	0.37	0.55	0.64	0.86	1.07	1.30
	F	0.00	0.00	0.17	0.17	0.21	0.29	0.47	0.68	0.80	0.88	1.05	1.25
	G	0.00	0.00	0.22	0.20	0.26	0.40	0.60	0.77	0.80	0.86	1.07	1.27
	H	0.00	0.00	0.13	0.17	0.23	0.30	0.39	0.39	0.43	0.47	0.63	0.82

Table C2.7: Average weight of reported salmon in inventory [kg], on county basis in 2015. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
>1 yr cohort	A	4.43	4.35	4.41	4.25	4.52	4.79	4.73	5.21	0.00	0.00	0.00	0.00
	B	3.88	3.98	4.08	4.23	4.55	4.73	5.25	5.03	2.89	0.00	0.00	0.00
	C	4.53	4.82	5.19	5.50	5.69	6.36	7.27	14.66	14.66	0.00	0.00	0.00
	D	4.96	5.28	5.53	5.88	6.50	7.73	13.34	11.10	10.44	9.51	9.09	0.00
	E	5.05	5.54	5.95	6.83	7.70	9.16	9.63	10.74	10.42	9.92	10.58	10.92
	F	4.66	5.04	5.29	5.53	5.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	G	4.48	4.79	5.17	5.46	5.82	4.26	11.91	12.38	13.71	4.90	5.14	5.39
	H	4.35	4.52	4.77	5.04	5.15	5.13	6.65	6.71	6.69	6.73	7.19	0.12
1 yr cohort	A	1.08	1.19	1.32	1.45	1.64	1.89	2.29	2.79	3.21	3.61	3.87	4.14
	B	0.98	1.09	1.24	1.39	1.58	1.83	2.22	2.73	3.06	3.45	3.76	3.90
	C	1.22	1.35	1.53	1.70	1.90	2.15	2.47	2.89	3.20	3.46	3.75	4.01
	D	1.44	1.60	1.81	2.02	2.21	2.25	2.55	2.85	3.22	3.47	3.85	4.14
	E	1.50	1.70	1.91	2.14	2.43	2.69	3.02	3.31	3.37	3.73	3.97	4.47
	F	1.44	1.60	1.78	2.00	2.19	2.33	2.55	3.01	3.48	3.91	4.25	4.52
	G	1.46	1.61	1.76	1.92	2.11	2.22	2.35	2.79	3.15	3.36	3.56	3.87
	H	0.98	1.13	1.30	1.49	1.70	1.90	2.25	2.59	3.01	3.45	3.81	4.13
0 yr cohort	A	0.10	0.11	0.14	0.18	0.14	0.16	0.24	0.38	0.52	0.63	0.76	0.87
	B	0.00	0.00	0.00	0.12	0.14	0.16	0.39	0.32	0.43	0.52	0.67	0.80
	C	0.13	0.16	0.19	0.14	0.14	0.19	0.27	0.39	0.53	0.68	0.88	1.02
	D	0.00	0.18	0.19	0.202	0.233	0.317	0.426	0.575	0.702	0.877	1.110	1.355
	E	0.12	0.15	0.15	0.15	0.18	0.23	0.32	0.53	0.74	0.97	1.26	1.53
	F	0.00	0.00	0.29	0.19	0.20	0.29	0.45	0.68	0.78	0.82	0.94	1.13
	G	1.26	1.42	0.30	0.18	0.27	0.36	0.53	0.76	0.86	1.00	1.25	1.47
	H	0.00	0.00	0.18	0.20	0.26	0.36	0.41	0.42	0.40	0.51	0.67	0.86

Table C2.8: Average weight of reported salmon in inventory [kg], on county basis in 2016. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
>1 yr cohort	**A**	4.34	4.45	4.39	4.56	4.72	5.02	5.67	6.04	6.16	0.00	0.00	0.00
	B	4.01	4.08	4.31	4.46	4.63	4.69	4.08	4.19	0.00	0.00	0.00	0.00
	C	4.28	4.62	5.00	5.29	5.38	5.38	5.21	4.73	4.28	2.66	2.23	1.42
	D	4.43	4.77	5.12	6.26	9.76	1.64	13.13	11.63	10.94	9.88	0.00	0.00
	E	4.76	5.44	5.97	6.15	8.38	9.18	10.05	9.35	9.29	10.47	9.38	9.91
	F	4.87	5.13	5.22	5.54	5.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	G	4.18	4.45	4.67	4.84	4.84	13.10	8.20	9.00	0.00	0.00	0.00	0.00
	H	4.50	4.84	5.17	5.53	6.03	6.67	8.34	8.32	8.77	8.82	7.97	7.64
1 yr cohort	**A**	0.99	1.09	1.21	1.32	1.49	1.76	2.21	2.63	3.14	3.56	3.80	3.91
	B	0.93	1.05	1.18	1.32	1.48	1.72	2.16	2.60	3.06	3.46	3.62	3.87
	C	1.18	1.33	1.50	1.68	1.93	2.18	2.50	2.87	3.20	3.46	3.61	4.02
	D	1.53	1.74	1.97	2.14	2.28	2.42	2.75	2.93	3.11	3.49	3.86	4.28
	E	1.77	1.97	2.18	2.40	2.57	2.82	3.06	3.41	3.64	4.08	4.48	4.78
	F	1.32	1.45	1.60	1.75	1.93	2.13	2.48	2.85	3.34	3.68	3.99	4.29
	G	1.69	1.87	2.07	2.28	2.49	2.63	2.80	3.06	3.36	3.63	3.93	4.26
	H	1.01	1.14	1.28	1.43	1.62	1.93	2.31	2.83	3.22	3.68	4.05	4.40
0 yr cohort	**A**	0.00	0.00	0.00	0.27	0.17	0.17	0.26	0.36	0.51	0.65	0.81	0.96
	B	0.25	0.30	0.39	0.16	0.18	0.22	0.32	0.40	0.53	0.71	0.87	1.05
	C	0.15	0.18	0.22	0.18	0.17	0.22	0.35	0.46	0.58	0.71	0.89	1.04
	D	0.00	0.00	0.28	0.267	0.287	0.427	0.540	0.685	0.704	0.850	1.046	1.261
	E	0.18	0.20	0.18	0.21	0.26	0.34	0.46	0.69	0.88	1.08	1.29	1.51
	F	0.00	0.00	0.23	0.24	0.23	0.32	0.50	0.73	0.86	0.94	1.12	1.33
	G	2.07	1.06	0.34	0.31	0.36	0.50	0.69	0.81	0.89	1.06	1.26	1.47
	H	0.00	0.00	0.24	0.25	0.25	0.35	0.43	0.54	0.58	0.65	0.83	1.00

Table C2.9: Average weight of reported salmon in inventory [kg], on county basis in 2017. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
>1 yr cohort	**A**	3.93	3.87	3.71	3.87	4.01	4.42	4.95	5.38	5.26	0.00	0.00	0.00
	B	4.11	4.37	4.59	4.87	5.16	5.14	5.57	5.46	0.00	0.00	0.00	0.00
	C	4.40	4.72	4.99	5.24	5.46	5.49	6.47	4.39	13.35	12.30	11.90	0.00
	D	4.69	5.04	5.45	6.12	13.75	16.08	17.15	14.11	13.33	12.50	11.77	0.00
	E	5.04	4.95	4.46	4.70	4.94	6.37	7.36	4.59	5.96	12.98	14.16	14.91
	F	4.56	4.66	4.81	4.57	0.00	0.00	0.00	0.00	0.00	3.15	0.00	0.00
	G	4.68	5.26	5.48	5.24	4.32	2.47	2.80	3.78	3.92	4.62	4.73	5.96
	H	4.75	4.94	5.07	5.20	5.70	6.57	10.06	10.06	10.06	0.00	0.00	0.00
1 yr cohort	**A**	1.10	1.22	1.34	1.49	1.67	1.92	2.38	2.98	3.42	3.86	4.21	4.53
	B	1.21	1.35	1.50	1.67	1.85	2.10	2.48	2.83	3.11	3.47	3.77	4.00
	C	1.18	1.33	1.49	1.68	1.91	2.11	2.45	2.81	3.10	3.35	3.68	4.00
	D	1.60	1.62	1.78	1.94	2.00	2.07	2.32	2.57	3.01	3.39	3.75	4.07
	E	1.73	1.92	2.16	2.39	2.64	2.93	3.15	3.47	3.79	4.04	4.07	4.28
	F	1.52	1.63	1.88	2.05	2.16	2.33	2.61	2.98	3.38	3.74	3.95	4.09
	G	1.64	1.80	1.97	2.13	2.31	2.49	2.68	3.07	3.41	3.79	4.07	4.46
	H	1.16	1.27	1.43	1.58	1.82	2.10	2.40	2.81	3.24	3.62	3.84	4.06
0 yr cohort	**A**	0.16	0.19	0.23	0.29	0.22	0.19	0.27	0.37	0.48	0.65	0.82	0.91
	B	0.34	0.44	0.55	0.19	0.21	0.25	0.35	0.47	0.66	0.78	0.99	1.17
	C	0.17	0.22	0.29	0.29	0.27	0.34	0.47	0.64	0.74	0.96	1.13	1.29
	D	0.00	0.20	0.21	0.237	0.267	0.342	0.483	0.649	0.852	1.070	1.255	1.481
	E	0.00	0.12	0.19	0.23	0.30	0.40	0.58	0.93	1.11	1.25	1.36	1.52
	F	0.00	0.00	0.33	0.26	0.26	0.36	0.51	0.70	0.81	0.89	1.01	1.16
	G	0.00	0.00	0.24	0.25	0.34	0.50	0.76	0.99	1.15	1.28	1.49	1.73
	H	0.00	0.00	0.25	0.32	0.43	0.58	0.62	0.62	0.49	0.58	0.74	0.89

Table C2.10: Average weight of reported salmon in inventory [kg], on county basis in 2018. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
>1 yr cohort	A	4.82	4.91	4.70	4.76	4.87	5.20	5.94	6.13	0.00	2.86	0.00	0.00
	B	4.33	4.66	4.93	5.15	5.39	5.92	6.78	0.00	0.00	0.00	0.00	0.00
	C	4.28	4.53	4.85	5.22	5.49	5.42	4.31	7.14	2.26	13.11	10.45	10.67
	D	4.49	4.78	4.99	5.66	6.17	11.35	11.24	10.64	10.64	10.58	0.00	0.00
	E	4.59	4.76	5.10	5.40	6.18	11.15	11.22	11.62	11.76	12.41	0.00	0.00
	F	4.19	4.42	4.53	4.29	7.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	G	4.63	5.00	4.79	3.13	12.76	9.93	5.78	0.77	6.26	7.86	8.19	9.90
	H	4.17	4.27	4.25	4.57	5.29	5.72	8.02	8.02	8.02	4.14	8.00	8.00
1 yr cohort	A	1.05	1.16	1.29	1.39	1.50	1.69	2.03	2.41	2.85	2.79	3.32	3.56
	B	1.29	1.41	1.52	1.58	1.75	2.04	2.43	2.89	3.26	3.46	3.64	3.91
	C	1.50	1.64	1.78	1.94	2.05	2.23	2.53	2.70	2.81	3.12	3.48	3.76
	D	1.68	1.88	2.10	2.29	2.54	2.73	2.89	3.09	3.43	3.68	3.89	4.24
	E	1.70	1.90	2.09	2.38	2.58	2.85	3.17	3.46	3.55	3.75	4.13	4.22
	F	1.33	1.45	1.53	1.65	1.88	2.07	2.34	2.73	3.07	2.93	3.68	4.06
	G	1.89	2.02	2.13	2.31	2.52	2.63	2.65	2.77	3.08	3.42	3.81	4.10
	H	1.01	1.11	1.19	1.33	1.54	1.72	2.06	2.52	2.99	3.49	3.95	4.30
0 yr cohort	A	0.14	0.18	0.22	0.20	0.20	0.20	0.23	0.32	0.47	0.60	0.69	0.81
	B	0.27	0.34	0.30	0.28	0.22	0.24	0.34	0.45	0.52	0.72	0.90	1.05
	C	0.12	0.20	0.23	0.24	0.23	0.28	0.40	0.51	0.68	0.84	1.03	1.18
	D	0.00	0.24	0.20	0.18	0.23	0.35	0.48	0.66	0.76	0.97	1.18	1.42
	E	0.08	0.20	0.21	0.27	0.27	0.34	0.48	0.70	0.94	1.15	1.42	1.68
	F	0.00	0.00	0.23	0.24	0.25	0.36	0.54	0.73	0.79	0.91	1.03	1.23
	G	0.00	1.99	0.30	0.28	0.35	0.50	0.66	0.82	0.95	1.12	1.36	1.59
	H	0.00	0.00	0.49	0.27	0.33	0.50	0.64	0.46	0.51	0.54	0.67	0.85

Table C2.11: Average weight of reported salmon in inventory [kg], on county basis in 2019. A: Finnmark; B: Troms; C: Nordland; D: Trøndelag; E: Møre & Romsdal; F: Sogn & Fjordane; G: Hordaland; H: Rogaland & Agder.

		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
>1 yr cohort	**A**	3.59	3.65	3.76	3.92	4.33	4.61	5.19	5.59	0.00	0.00	0.00	0.00
	B	4.16	4.28	4.42	4.47	4.76	4.81	4.98	0.00	0.00	0.00	0.00	0.00
	C	4.01	4.18	4.33	4.39	4.42	4.56	3.56	5.61	7.37	11.35	11.81	12.98
	D	4.53	4.82	5.26	6.17	12.56	12.10	11.49	10.34	11.44	11.09	0.00	0.00
	E	4.25	4.18	4.26	6.65	10.87	10.45	11.10	11.90	13.00	13.77	13.65	13.54
	F	4.35	4.41	4.51	4.91	6.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	G	4.34	4.54	4.86	5.43	6.03	5.39	0.00	0.00	0.00	0.00	0.00	0.00
	H	4.62	4.96	5.32	5.69	5.91	8.28	8.23	8.21	0.00	8.21	8.17	8.09
1 yr cohort	**A**	0.95	1.07	1.20	1.35	1.53	1.74	2.13	2.52	2.92	3.25	3.40	3.55
	B	1.20	1.33	1.47	1.63	1.79	2.04	2.45	2.87	3.16	3.55	3.82	4.12
	C	1.36	1.52	1.70	1.91	2.16	2.41	2.76	3.05	3.30	3.56	3.82	4.10
	D	1.66	1.91	2.12	2.32	2.48	2.67	2.87	3.09	3.39	3.77	4.06	4.46
	E	1.86	2.07	2.31	2.58	2.79	3.00	3.27	3.62	3.84	3.84	3.87	4.18
	F	1.37	1.52	1.65	1.81	1.96	2.15	2.47	2.92	3.34	3.65	3.94	4.24
	G	1.77	1.93	2.08	2.26	2.52	2.79	2.79	2.93	3.17	3.40	3.73	3.90
	H	1.01	1.13	1.19	1.27	1.50	1.80	2.20	2.65	3.07	3.48	3.77	3.95
0 yr cohort	**A**	0.27	0.35	0.42	0.20	0.20	0.25	0.33	0.43	0.64	0.75	0.85	0.95
	B	0.00	0.00	0.53	0.24	0.20	0.26	0.39	0.47	0.59	0.75	0.89	0.96
	C	0.27	0.31	0.37	0.41	0.31	0.39	0.56	0.63	0.80	0.93	1.11	1.25
	D	0.20	0.24	0.27	0.25	0.30	0.38	0.49	0.66	0.80	1.05	1.26	1.50
	E	0.00	0.00	0.84	0.34	0.38	0.42	0.54	0.77	1.03	1.11	1.32	1.54
	F	0.08	0.11	0.24	0.22	0.27	0.36	0.58	0.76	0.89	1.00	1.10	1.30
	G	0.08	0.14	0.23	0.25	0.33	0.49	0.69	0.90	1.09	1.19	1.45	1.71
	H	0.00	0.00	0.37	0.33	0.42	0.60	0.75	0.69	0.78	0.80	0.93	1.11

Appendix D: Value estimation of lost salmon 2014-2019

The NASDAQ Salmon Index (NQSALMON) is the weighted average of weekly reported sales prices and corresponding volumes in fresh Atlantic Superior Salmon, head on gutted (HOG) [126]. Reports from a panel of Norwegian salmon exporters forms the basis for the index. The panel represents the total export out of Norway. In 2014, 2015, and 2017 the index prices were based on reported volumes of 275 000, 219 000, and 231 000 tonnes, respectively (32, 26, and 27 percent of total production volume, respectively) [140]. A typical way of estimating values lost in Norwegian aquaculture due to mortality in the sea phase is to multiply the number of total salmon lost in the sea phase one year with the average export price and the average slaughter weight. As salmon often die long before reaching an average slaughter weight of 5 kg, the calculation is at best estimating the average potential value of the salmon. Identifying the export price a lost individual could have at the time of death, according to the individual salmon's size and quality, would form the basis for an accurate estimate of the value lost.

Production loss data maid available to the public, in the NDFs "Biomass statistics" [71], are monthly figures. To estimate the value of salmon lost on a monthly basis, the NASDAQ Salmon Index average weekly prices are converted into average monthly prices. The average monthly export prices are found in tables, or matrices, **F1.1** to **F1.6** (different weight categories divided into columns). Figures before week 14 in 2013 were not calculated by NASDAQ Salmon Index and figures from 2014-2019 are therefore used. NASDAQ uses Head-on-Gutted (HOG) weight distributions, while NDFs inventory data [196] are assumed reported live weight (LWE) figures. The conversion ratio HOG to LWE is according to NS 9417:2012 1.200 [160].

The NDF Excel files with production loss, distinguishes between four loss categories: "dead fish", "throw outs", "escapes" and "other". Only losses in the "dead fish" category are used in the calculations in the Matlab script found at the end of this appendix. The same division into cohorts, seen in Appendix E, is used. The average weight of the lost salmon comes from inventory data reported to NDF [196], found in tables **E2.6** to **E2.11** in Appendix E. Since the average weight of salmon in the farmers' inventory is reported at the end of each month, the weight has typically increased during the month. All inventory data in the Matlab script is therefore reduced with 10 percent, before any further calculation. Since the NASDAQ Salmon index only consists of salmon weighing more than 1 kg, all salmon weighing on average less than this is omitted from the calculation.

Innrapporterte svinntall i januar 2019. Antall i 1000 stk

	Laks											
	Tidligere utsett				Fjorårets utsett				Årets utsett			
Fylke	Dødfisk	Utkast	Rømming	Annet	Dødfisk	Utkast	Rømming	Annet	Dødfisk	Utkast	Rømming	Annet
Finnmark	57	13	0	9	188	0	0	2	0	0	0	0
Troms	50	4	0	-16	294	0	0	8	0	0	0	0
Nordland	66	4	0	5	655	0	0	0	104	0	0	0
Trøndelag	281	28	16	-45	277	0	0	376	8	0	0	0
Møre og Romsdal	23	17	0	-51	289	63	0	30	0	0	0	0
Sogn og Fjordane	102	71	0	14	199	1	0	-12	1	0	0	0
Hordaland	228	86	0	32	709	15	0	-6	0	0	0	0
Rogaland og Agder	219	57	0	16	90	0	0	0	0	0	0	0
Totalt	1,026	280	16	-37	2,702	79	0	400	113	0	0	0

Figure D.1:

Table D1.1: NASDAQ Salmon Index average monthly prices [NOK/kg] of different weight classes [kg], in 2014.

	1-2	**2-3**	**3-4**	**4-5**	**5-6**	**6-7**	**7-8**	**8-9**	**9 +**
Jan	39.29	45.74	49.38	50.51	51.10	51.82	52.04	51.95	51.88
Feb	38.29	43.91	47.35	48.32	48.88	49.62	49.85	49.60	49.60
Mar	34.75	40.28	44.19	44.58	44.68	44.52	44.33	44.00	43.69
Apr	35.98	41.77	45.82	46.07	46.10	45.79	45.48	44.78	44.46
May	30.37	35.19	39.71	39.97	39.95	39.52	38.95	38.32	37.88
Jun	27.60	31.22	35.42	35.92	35.82	35.01	34.36	33.64	32.96
Jul	29.77	34.30	38.31	39.81	41.31	44.33	44.73	44.82	44.60
Aug	23.48	27.37	30.77	32.95	35.50	42.83	43.82	44.34	42.95
Sep	26.43	28.79	31.81	32.89	33.41	36.87	38.86	39.24	38.56
Oct	27.71	30.65	33.55	33.98	34.02	33.88	34.73	34.75	34.48
Nov	33.80	37.34	40.66	40.59	40.33	38.45	38.16	38.31	38.50
Dec	37.16	41.59	45.23	45.74	45.77	46.19	45.98	45.94	44.25

Table D1.2: NASDAQ Salmon Index average monthly prices [NOK/kg] of different weight classes [kg], in 2015.

	1-2	**2-3**	**3-4**	**4-5**	**5-6**	**6-7**	**7-8**	**8-9**	**9 +**
Jan	33.39	39.23	42.84	43.14	43.28	43.84	44.10	43.90	43.85
Feb	32.31	37.42	40.42	40.39	40.60	40.76	40.98	40.76	41.18
Mar	32.35	37.31	40.50	40.59	40.53	39.95	39.61	39.41	39.58
Apr	31.31	34.70	37.44	37.56	37.46	36.87	36.44	36.11	36.36
May	29.66	33.66	36.97	37.14	37.16	36.41	36.00	35.45	35.01
Jun	30.14	34.10	38.74	40.36	40.87	40.89	40.94	40.52	39.51
Jul	27.08	34.54	41.30	44.94	47.17	52.75	53.17	53.24	52.42
Aug	30.35	35.08	39.95	42.46	44.51	50.21	51.02	51.37	49.64
Sep	29.19	33.88	38.10	39.57	41.44	46.60	48.95	49.61	49.75
Oct	23.25	32.40	39.85	41.44	42.37	44.71	46.10	46.85	47.17
Nov	28.30	35.63	42.20	43.84	44.63	47.34	49.66	50.12	50.35
Dec	38.36	47.32	51.94	53.18	53.85	54.92	55.46	54.49	53.84

Table D1.3: NASDAQ Salmon Index average monthly prices [NOK/kg] of different weight classes [kg], in 2016.

	1-2	**2-3**	**3-4**	**4-5**	**5-6**	**6-7**	**7-8**	**8-9**	**9 +**
Jan	38.99	50.78	55.21	56.34	57.41	59.82	60.84	61.70	61.98
Feb	40.76	51.87	56.03	57.41	57.89	58.72	59.10	58.97	59.01
Mar	45.83	57.21	62.23	63.39	63.90	64.63	64.49	64.83	64.70
Apr	41.41	50.52	58.04	59.68	60.14	60.74	60.76	60.47	60.46
May	44.04	57.52	63.49	65.08	65.60	65.75	65.57	65.31	63.40
Jun	45.92	60.92	68.21	70.27	71.94	73.83	73.64	73.32	72.09
Jul	45.26	61.03	68.42	71.71	76.44	83.09	84.08	85.28	86.02
Aug	41.64	51.23	55.91	58.10	62.45	74.03	75.10	75.39	76.65
Sep	40.83	47.47	52.57	54.23	56.22	62.46	65.36	65.82	67.75
Oct	43.58	54.05	61.42	64.30	66.72	71.81	75.48	76.55	77.13
Nov	47.60	58.87	63.72	65.02	66.44	69.86	70.52	70.86	72.31
Dec	53.53	65.82	73.64	76.41	78.51	83.25	84.73	85.54	83.84

Table D1.4: NASDAQ Salmon Index average monthly prices [NOK/kg] of different weight classes [kg], in 2017.

	1-2	**2-3**	**3-4**	**4-5**	**5-6**	**6-7**	**7-8**	**8-9**	**9 +**
Jan	50.82	65.51	73.71	75.66	77.50	78.50	81.47	84.15	84.04
Feb	50.12	60.90	64.32	65.03	65.13	64.81	64.81	64.78	64.89
Mar	51.03	57.21	61.63	61.82	61.75	60.74	60.27	59.85	59.02
Apr	53.19	59.68	64.15	64.05	64.08	63.92	63.53	63.88	63.33
May	53.83	64.06	70.25	71.49	72.06	72.35	72.41	72.87	72.95
Jun	52.05	62.54	69.99	70.92	71.44	71.48	70.83	70.90	70.33
Jul	44.68	53.37	61.91	63.80	65.50	69.96	70.36	70.74	69.54
Aug	42.73	47.90	52.88	54.59	56.65	63.25	64.86	65.99	65.98
Sep	42.52	45.58	50.57	52.24	54.46	63.01	65.41	67.16	67.23
Oct	40.89	45.81	51.15	52.56	53.51	55.90	57.78	61.00	61.36
Nov	38.61	41.88	46.58	46.96	46.92	46.65	46.57	47.15	47.21
Dec	37.96	43.31	49.79	51.78	52.90	54.48	54.88	54.87	55.07

Table D1.5: NASDAQ Salmon Index average monthly prices [NOK/kg] of different weight classes [kg], in 2018.

	1-2	**2-3**	**3-4**	**4-5**	**5-6**	**6-7**	**7-8**	**8-9**	**9 +**
Jan	40.21	46.04	52.92	54.48	55.75	57.91	57.92	57.81	57.10
Feb	43.02	49.55	56.98	58.87	60.49	61.27	61.53	61.88	61.37
Mar	52.40	63.62	70.81	71.74	71.84	70.39	69.67	69.35	68.02
Apr	53.51	62.06	70.41	71.12	71.47	70.56	70.02	69.63	69.00
May	51.65	63.81	74.59	76.83	77.77	77.77	77.58	77.73	76.76
Jun	41.80	50.02	59.08	60.90	62.05	63.19	63.51	64.14	63.85
Jul	37.75	45.41	52.53	54.31	55.65	58.02	58.40	58.87	59.55
Aug	38.70	43.79	50.80	52.83	55.00	62.30	65.61	68.11	67.66
Sep	43.60	50.87	57.00	59.41	62.59	73.15	77.82	80.45	80.86
Oct	42.06	48.87	54.43	56.43	59.16	67.92	73.25	76.87	76.69
Nov	37.04	44.42	50.97	53.35	55.50	61.77	64.64	67.74	69.68
Dec	45.65	51.59	57.06	59.29	61.89	65.24	69.05	72.89	74.57

```
close all;
clear all;

%%%LOAD LOSS DATA%%%
% Tables E1.6-E1.11 in Appendix E.
L_14 = importdata('Loss_2014.txt');
L_15 = importdata('Loss_2015.txt');
L_16 = importdata('Loss_2016.txt');
L_17 = importdata('Loss_2017.txt');
L_18 = importdata('Loss_2018.txt');
L_19 = importdata('Loss_2019.txt');

% Put all loss data in a 24x72 matrix
L_all = [L_14, L_15, L_16, L_17, L_18, L_19];

% Sum all losses into monthly national losses
Sum_L = sum(L_all);

% Sum monthly losses into yearly national losses
Sum_L_yr = [ sum(Sum_L(1:12)) sum(Sum_L(13:24)) sum(Sum_L(25:36))...
             sum(Sum_L(37:48)) sum(Sum_L(49:60)) sum(Sum_L(61:72))];

%%%LOAD INVENTORY DATA [Av. size in kg]%%%
% Load average weight data in live weight equivalent (LWE)
% Tables E2.6-E6.11 in Appendix E

HOG = 1/1.2;    % Head-on Gutted conversion factor (NS 9417:2012)
                % Av. sizes are LWE. HOG is basis for calculation NOK lost
W_f = 0.9;      % Includes a 10% additional size reduction

B_14 = importdata('Behold_2014.txt');
B_15 = importdata('Behold_2015.txt');
B_16 = importdata('Behold_2016.txt');
B_17 = importdata('Behold_2017.txt');
B_18 = importdata('Behold_2018.txt');
B_19 = importdata('Behold_2019.txt');

% Put all inventory data in a 24x72 matrix
B_all = [B_14, B_15, B_16, B_17, B_18, B_19]*HOG*W_f;

% Remove all values below 1 kg.

for i = 1:24
    for j = 1:72
        if B_all(i,j) < 1.0
           B_all(i,j) = 0;
        end
    end
end

%%%LOAD NASDAQ EXPORT PRICES%%%
% Tables F1.6-F1.11 in Appendix F
NAS_14 = importdata('NAS_2014.txt'); NAS_14 = transpose(NAS_14);
NAS_15 = importdata('NAS_2015.txt'); NAS_15 = transpose(NAS_15);
NAS_16 = importdata('NAS_2016.txt'); NAS_16 = transpose(NAS_16);
NAS_17 = importdata('NAS_2017.txt'); NAS_17 = transpose(NAS_17);
NAS_18 = importdata('NAS_2018.txt'); NAS_18 = transpose(NAS_18);
NAS_19 = importdata('NAS_2019.txt'); NAS_19 = transpose(NAS_19);

% Matrix with all average monthly values [9x72]
```

```
% Columns are the months from January 2014 to December 2019.
% Rows are the export price for the nine different weight classes.
NAS_all = [NAS_14, NAS_15, NAS_16, NAS_17, NAS_18, NAS_19];

%%%FINDING VALUE OF FISH LOST%%%
% Find the HOG size in B_all and sets monthly value of that weight in
% a conversion matrix. The conversion matrix' columns are the months
% from January 2014 to December 2019. The matrix' rows are the eight
% Norwegian salmon farming counties, divided into salmon cohorts
% (1-8 = >1 yr cohort, 9-16 = 1 yr cohort, 17-24 = 0 yr cohort).
CONV = zeros(24,72);

for i = 1:24
    for j = 1:72

        if B_all(i,j) ≥ 9
            CONV(i,j) = NAS_all(9,j);
        elseif B_all(i,j) < 9 && B_all(i,j) ≥ 8
            CONV(i,j) = NAS_all(7,j);
        elseif B_all(i,j) < 8 && B_all(i,j) ≥ 7
            CONV(i,j) = NAS_all(7,j);
        elseif B_all(i,j) < 7 && B_all(i,j) ≥ 6
            CONV(i,j) = NAS_all(6,j);
        elseif B_all(i,j) < 6 && B_all(i,j) ≥ 5
            CONV(i,j) = NAS_all(5,j);
        elseif B_all(i,j) < 5 && B_all(i,j) ≥ 4
            CONV(i,j) = NAS_all(4,j);
        elseif B_all(i,j) < 4 && B_all(i,j) ≥ 3
            CONV(i,j) = NAS_all(3,j);
        elseif B_all(i,j) < 3 && B_all(i,j) ≥ 2
            CONV(i,j) = NAS_all(2,j);
        elseif B_all(i,j) < 2 && B_all(i,j) ≥ 1
            CONV(i,j) = NAS_all(1,j);

        end
    end

end

% Finding the total value lost of all cohorts in each county
% Value lost = Average weight * No. of lost individuals *...
% average, weight specific, monthly export price
Value = ((B_all.*L_all).*CONV)*(1/1000); %Value in million NOK

% Monthly national losses
SUM_N = sum(Value);

% Yearly losses
SUM_N_YR = [sum(SUM_N(1:12)) sum(SUM_N(13:24)) sum(SUM_N(25:36))...
            sum(SUM_N(37:48)) sum(SUM_N(49:60)) sum(SUM_N(61:72))];

% Converting pre-2019 loss figures to 2019 figures
% using the KPI index (url: https://www.ssb.no/kpi)
KPI = [1.132 1.108 1.069 1.05 1.022 1];
```

Appendix E: Identifying areas with largest loss concentration

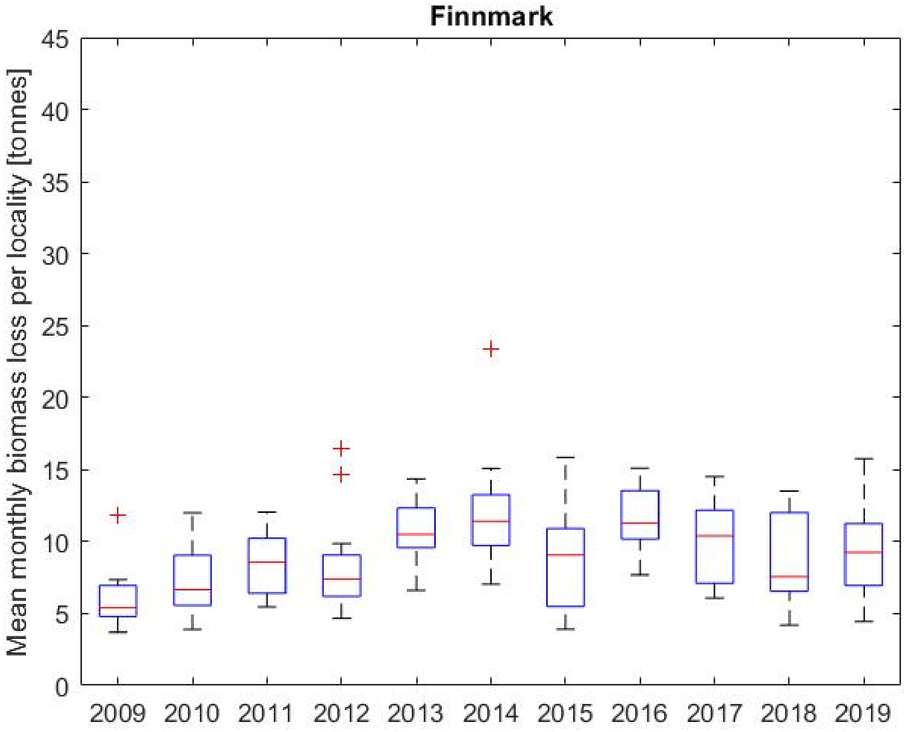

Figure E1:Box plot of yearly biomass losses in Finnmark, 2009-2019.

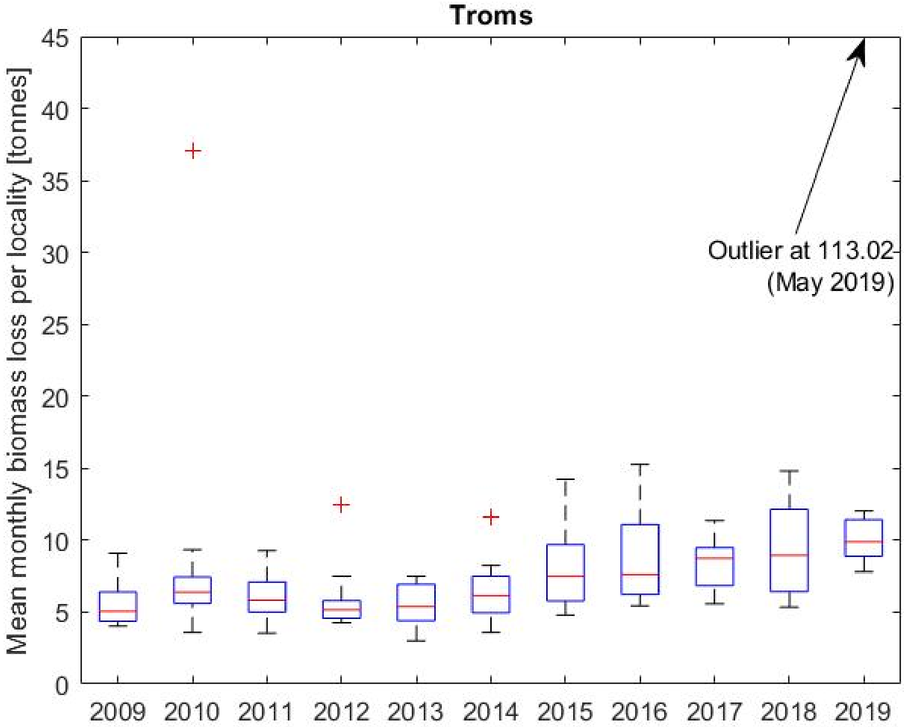

Figure E2:Box plot of yearly biomass losses in Troms, 2009-2019.

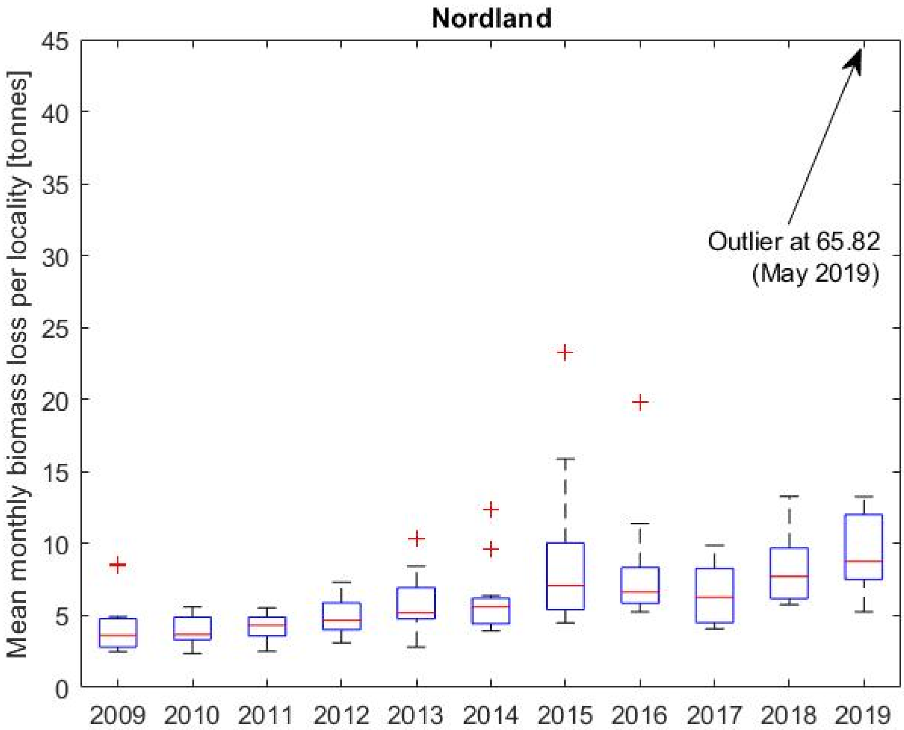

Figure E3:Box plot of yearly biomass losses in Nordland, 2009-2019.

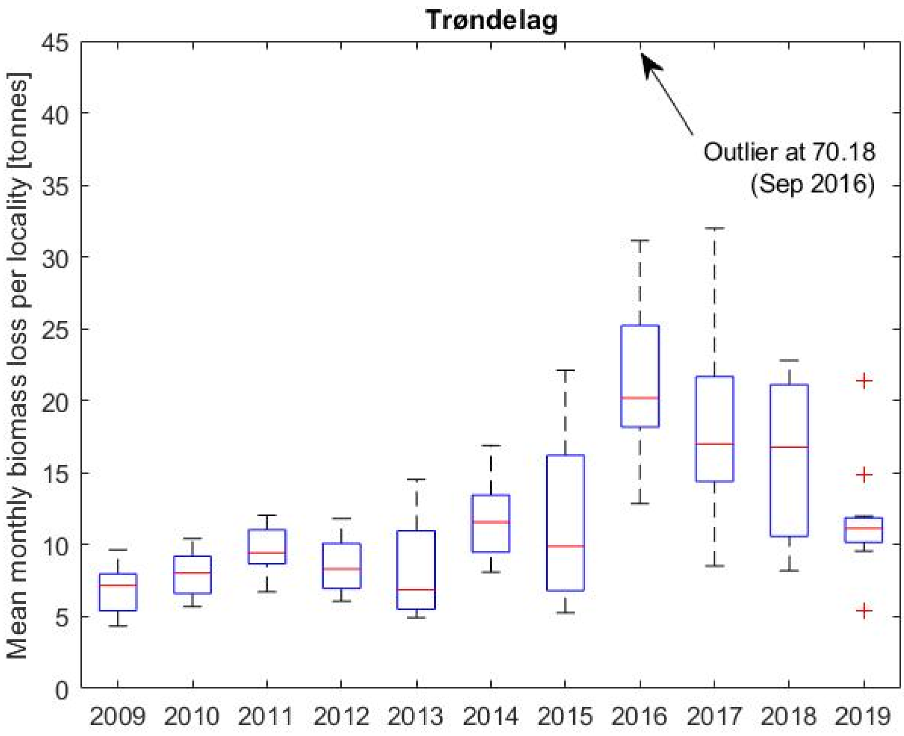

Figure E4:Box plot of yearly biomass losses in Trøndelag, 2009-2019.

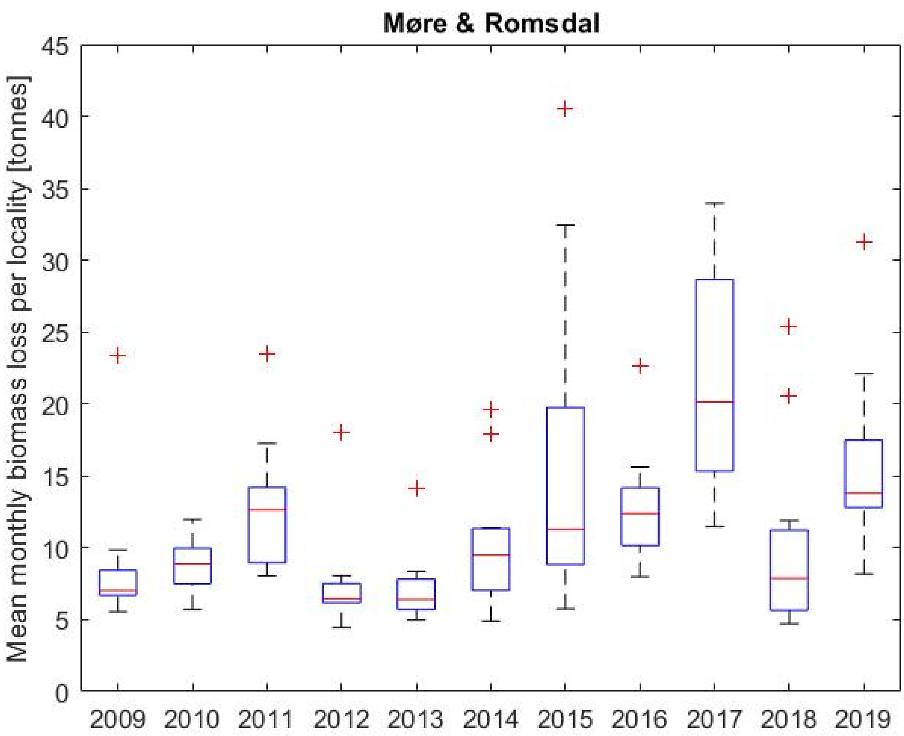

Figure E5:Box plot of yearly biomass losses in Møre & Romsdsdal, 2009-2019.

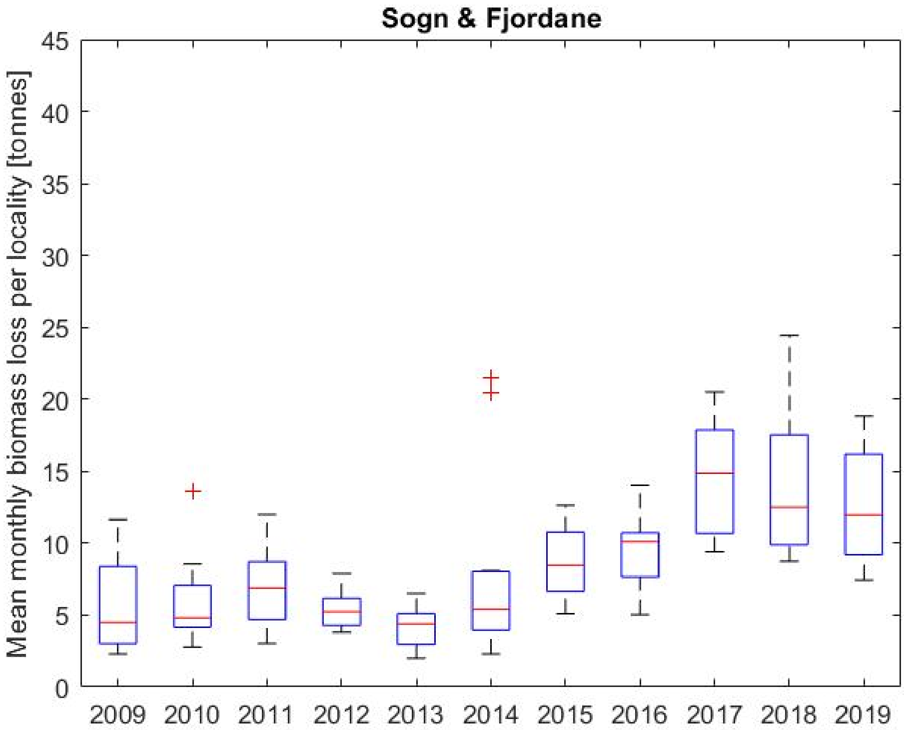

Figure E6:Box plot of yearly biomass losses in Sogn & Fjordane, 2009-2019.

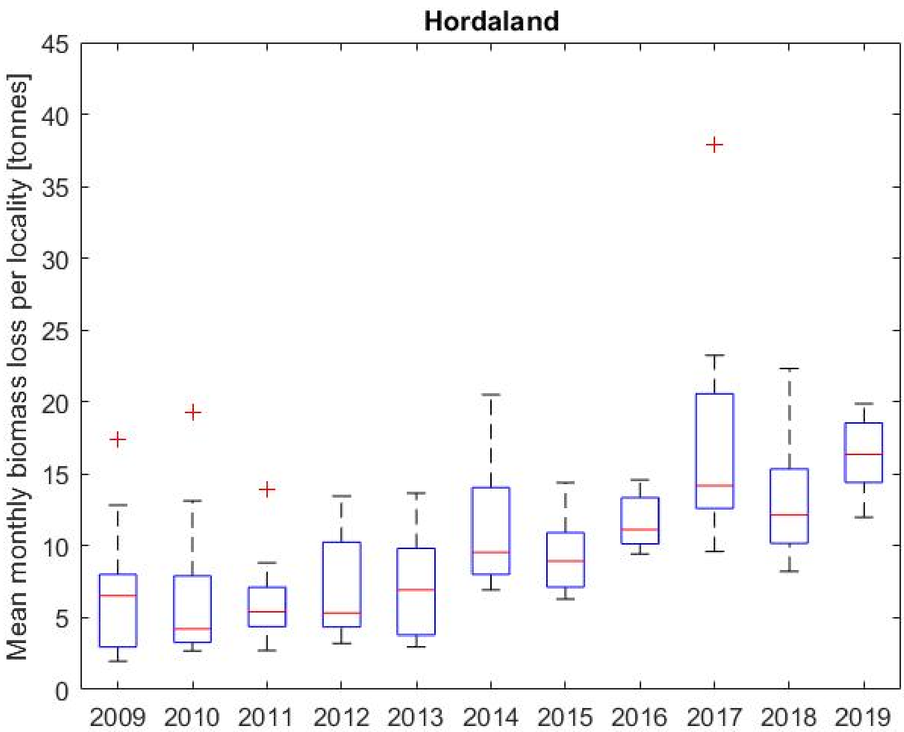

Figure E7:Box plot of yearly biomass losses Hordaland, 2009-2019.

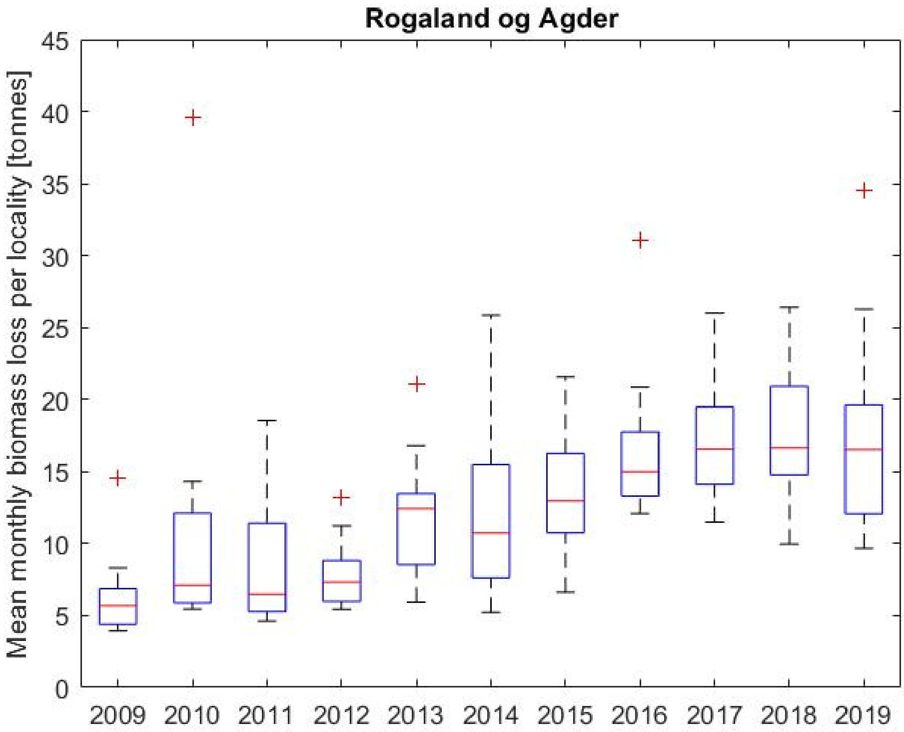

Figure E8:Box plot of yearly biomass losses in Rogaland & Agder, 2009-2019.

Table G1: Monthly average production cages in use, on county basis. From 2009-2019.

2009

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A	226	211	196	190	243	277	300	303	311	300	285	283
B	365	353	335	336	381	456	455	452	444	432	406	382
C	796	751	694	690	820	881	878	847	890	897	887	828
D	485	469	469	452	548	555	554	563	577	577	562	527
E	343	327	310	321	335	323	355	358	375	359	341	318
F	297	287	271	295	346	346	324	327	348	358	354	335
G	761	717	683	737	789	730	678	647	682	721	739	720
H	384	368	361	366	383	353	333	335	370	413	400	381

2010

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A	245	246	228	245	274	301	309	311	300	289	277	257
B	360	341	321	319	383	437	435	432	417	420	415	393
C	774	745	709	696	784	820	852	847	903	927	908	867
D	496	464	432	430	521	517	533	559	582	582	588	586
E	301	296	298	302	324	311	331	333	343	472	336	334
F	312	332	292	326	342	331	317	311	304	318	347	325
G	685	699	670	743	802	756	674	679	726	785	823	798
H	351	347	312	310	329	278	294	290	341	387	372	373

2011

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

Table G1 continued from previous page

A	246	228	218	218	244	284	308	320	314	304	294	280
B	375	360	338	335	358	428	427	435	436	446	421	398
C	838	776	759	757	860	860	871	890	933	929	880	836
D	568	539	508	512	565	591	580	568	594	593	561	520
E	321	308	304	304	355	355	356	352	354	346	322	288
F	317	306	297	289	317	321	309	306	324	342	355	338
G	757	743	674	773	839	787	692	716	800	838	823	777
H	342	337	321	319	349	334	280	273	329	351	367	347

2012

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
A	272	256	223	232	284	303	356	374	366	348	334	327
B	380	353	340	337	369	421	411	436	459	458	441	405
C	791	739	690	719	870	881	848	834	869	889	854	802
D	489	461	422	445	510	533	527	524	567	561	549	530
E	268	257	272	268	301	312	296	300	336	345	358	346
F	316	302	272	276	309	299	302	325	336	334	337	339
G	760	718	719	829	828	820	743	745	800	837	803	740
H	360	319	304	293	283	295	267	324	346	384	387	383

2013

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
A	296	259	229	223	231	287	311	317	316	314	302	294
B	392	370	352	351	402	437	454	461	463	475	441	425
C	759	729	684	663	767	876	863	870	869	859	803	745
D	508	493	496	523	569	603	611	630	645	643	620	619
E	323	318	302	301	353	344	351	373	337	349	310	313
F	325	312	291	283	308	307	304	313	313	338	339	317
G	707	668	658	732	771	730	652	642	723	788	775	742
H	362	342	319	324	304	292	270	297	340	374	374	360

2014

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
A	271	250	228	211	249	284	289	322	317	307	292	274
B	398	371	348	353	399	428	437	455	480	485	462	475
C	714	684	658	632	745	756	747	800	835	772	767	727
D	581	542	523	539	593	591	573	565	581	553	507	487
E	294	281	275	305	346	325	344	354	442	451	456	447
F	296	285	268	273	298	304	292	296	301	320	318	305
G	708	693	737	813	815	749	690	710	739	713	704	669
H	343	305	283	283	286	280	269	293	322	389	389	371

2015

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
A	256	225	203	204	253	313	332	332	311	305	298	292
B	412	385	349	353	407	452	458	476	482	497	475	440
C	703	669	616	615	695	739	767	785	793	794	741	700
D	467	428	417	461	513	490	487	506	582	596	600	588
E	442	428	437	453	476	477	408	365	311	338	293	288
F	294	277	258	265	296	288	269	277	302	335	344	322

Table G1 continued from previous page

G	627	598	588	724	741	680	636	654	705	727	696	665
H	361	342	321	316	304	276	277	306	360	386	381	342

2016

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A	267	250	225	211	242	273	286	291	292	301	287	272
B	410	392	351	370	403	440	454	476	509	502	473	442
C	673	639	603	614	710	730	703	744	787	765	744	727
D	571	556	551	541	553	537	529	497	483	474	472	457
E	264	240	258	334	377	388	389	403	417	444	451	440
F	305	278	269	272	316	311	305	294	317	339	333	312
G	635	605	664	729	699	662	603	630	664	662	647	625
H	330	297	270	261	266	250	268	292	330	362	358	349

2017

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A	259	245	231	230	258	315	328	335	354	347	326	316
B	438	419	396	421	468	489	491	499	472	496	466	448
C	704	686	669	698	741	787	798	820	838	856	843	844
D	411	370	376	386	462	448	462	561	612	643	663	639
E	411	375	346	364	399	414	409	373	354	341	333	334
F	302	290	259	260	284	266	268	271	293	337	328	317
G	609	577	627	686	689	646	584	593	627	659	641	613
H	325	283	290	279	276	230	234	241	301	330	319	294

2018

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A	301	281	259	255	266	296	324	332	325	341	348	344
B	430	415	404	391	430	453	441	506	530	511	488	483
C	794	730	710	710	738	830	814	807	822	905	911	909
D	625	602	574	575	631	607	559	546	549	521	489	445
E	293	286	320	337	376	395	365	393	389	434	431	488
F	287	270	260	267	286	280	274	279	296	300	310	306
G	592	564	634	660	657	630	604	624	662	688	684	648
H	282	260	232	233	221	207	211	246	274	319	323	294

2019

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A	333	319	304	307	352	383	393	387	364	366	356	343
B	462	441	418	428	461	478	455	486	490	486	473	469
C	866	834	779	761	874	876	853	883	882	900	884	867
D	427	397	379	445	475	493	520	583	639	647	676	657
E	465	446	441	403	443	445	412	390	360	322	293	208
F	290	267	261	313	308	288	278	290	310	318	322	282
G	602	557	600	659	686	644	596	581	604	657	636	562
H	276	252	248	251	242	220	235	263	292	303	302	272

Table G2: Monthly average production locations in use, on county basis. From 2009-2019.

2009

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A	27	26	23	20	28	30	32	32	33	34	33	34
B	52	50	48	53	57	60	56	59	59	58	55	52
C	105	99	96	103	118	120	115	116	117	113	112	106
D	72	68	70	66	83	82	78	79	85	83	80	73
E	60	55	54	57	56	53	56	60	65	66	63	59
F	48	45	42	50	54	53	49	51	57	59	59	53
G	125	118	117	131	139	130	122	119	131	137	138	133
H	52	49	49	55	54	51	50	50	59	62	58	54

2010

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A	31	31	28	31	36	40	39	40	39	39	37	34
B	48	47	46	50	55	57	51	59	55	53	53	50
C	96	96	95	98	109	105	105	107	117	121	117	113
D	68	64	62	73	80	77	80	82	84	85	84	85
E	54	51	54	58	63	59	61	62	64	69	63	62
F	49	49	46	51	54	49	46	49	54	57	58	55
G	127	124	127	138	143	133	118	120	131	135	136	129
H	51	52	50	51	55	46	46	46	59	62	59	59

2011

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A	35	32	31	33	36	40	39	39	43	40	37	37
B	49	45	44	47	52	56	54	59	57	53	53	49
C	108	103	101	110	131	124	120	116	122	121	116	111
D	82	77	74	78	92	93	87	91	99	99	96	85
E	56	55	58	60	63	61	59	63	64	61	57	54
F	52	49	48	51	55	49	48	51	58	62	63	59
G	122	117	111	137	144	136	124	128	149	154	153	144
H	55	54	51	54	59	61	46	46	55	56	57	55

2012

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A	36	34	30	32	41	42	45	45	45	42	42	42
B	49	45	44	49	55	55	53	57	57	55	56	51
C	107	99	95	109	128	122	111	116	123	122	117	112
D	75	74	76	84	85	84	82	88	95	92	85	77
E	51	46	54	55	55	55	51	52	59	60	62	57
F	54	53	51	55	56	51	51	54	61	62	62	58
G	139	131	129	148	145	138	131	127	145	145	143	132
H	56	51	49	49	50	58	48	55	59	61	59	59

2013

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A	41	36	30	31	34	41	41	40	42	40	39	39
B	50	44	44	49	56	56	57	56	56	58	57	56
C	106	105	97	94	109	115	109	114	120	120	113	101

Table G2 continued from previous page

D	74	71	77	79	87	82	85	96	100	93	86	83
E	56	54	50	50	56	58	56	59	60	55	50	47
F	56	54	52	49	55	51	50	57	63	61	60	54
G	124	117	117	138	141	129	121	118	140	139	136	131
H	54	54	54	55	54	49	43	50	60	61	62	60

2014

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A	38	34	33	30	39	40	40	43	43	41	40	38
B	53	45	45	51	58	58	52	56	56	58	61	58
C	99	94	90	101	105	102	102	116	123	114	110	104
D	83	79	81	92	96	89	91	96	96	88	76	76
E	42	42	48	56	55	53	57	60	64	65	68	64
F	52	51	53	50	51	50	50	53	58	54	54	54
G	128	128	132	142	140	129	121	122	131	125	119	116
H	61	54	50	52	49	52	48	53	56	62	62	60

2015

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A	37	33	30	29	36	42	44	43	41	39	41	41
B	53	49	46	49	59	58	58	58	60	62	59	56
C	103	100	96	98	105	106	106	111	114	105	101	93
D	76	76	77	80	82	75	77	82	87	83	85	82
E	60	60	61	68	69	69	68	66	61	51	45	43
F	52	51	49	50	54	50	47	54	62	66	68	64
G	107	106	106	135	134	125	120	122	137	136	131	126
H	58	55	55	54	52	46	44	54	59	61	61	58

2016

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A	38	35	33	27	35	40	42	43	41	39	41	38
B	53	53	49	55	57	57	60	65	64	65	64	60
C	88	84	82	92	104	99	99	106	114	106	101	95
D	82	81	82	84	81	80	79	78	74	71	72	71
E	41	37	43	47	53	55	60	64	67	68	67	65
F	60	53	51	49	55	53	54	55	62	63	61	59
G	119	120	141	140	131	125	119	128	132	124	119	114
H	55	53	49	48	44	40	45	51	57	59	58	57

2017

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A	35	34	31	31	40	48	48	48	49	48	49	46
B	59	58	56	65	67	62	62	63	61	64	61	60
C	97	97	91	97	106	107	113	118	125	123	119	116
D	67	64	67	65	66	67	74	86	94	97	98	95
E	65	62	65	66	70	68	69	63	64	57	47	44
F	57	52	51	53	53	52	53	59	63	65	65	63
G	108	106	122	130	128	120	115	124	128	128	126	122
H	52	45	49	44	43	36	37	42	53	52	52	51

2018

Table G2 continued from previous page

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A	42	38	34	34	40	44	45	45	42	49	48	46
B	57	57	58	58	66	60	60	70	70	69	64	65
C	112	111	109	111	113	116	117	124	119	119	121	122
D	93	91	89	89	94	94	96	93	95	87	81	75
E	38	38	43	43	50	53	58	62	68	74	70	70
F	57	53	56	53	54	50	52	53	59	58	57	56
G	116	112	130	124	122	118	115	120	120	126	119	116
H	46	44	41	45	41	35	36	44	51	55	55	53

2019

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A	44	43	41	43	49	54	55	52	46	50	51	51
B	62	59	56	61	62	63	61	64	67	68	68	65
C	123	122	115	111	124	122	124	138	135	130	129	125
D	73	69	66	75	75	79	88	96	99	99	98	96
E	70	65	64	66	67	65	63	57	56	49	42	38
F	54	51	55	61	60	54	54	61	65	66	70	63
G	104	97	116	124	127	122	115	119	122	129	125	113
H	51	48	46	44	41	35	37	47	48	52	54	49

Matlab code G1: Biomass loss estimation

```
close all;
clear all;

%%%LOAD LOSS DATA%%%
% Tables E1.1-E1.11 in Appendix E.
L_09 = importdata('Loss_2009.txt');
L_10 = importdata('Loss_2010.txt');
L_11 = importdata('Loss_2011.txt');
L_12 = importdata('Loss_2012.txt');
L_13 = importdata('Loss_2013.txt');
L_14 = importdata('Loss_2014.txt');
L_15 = importdata('Loss_2015.txt');
L_16 = importdata('Loss_2016.txt');
L_17 = importdata('Loss_2017.txt');
L_18 = importdata('Loss_2018.txt');
L_19 = importdata('Loss_2019.txt');

% Put all loss data in a 24x120 matrix
L_all = [L_09, L_10, L_11, L_12, L_13,...
           L_14, L_15, L_16, L_17, L_18, L_19];

%%%LOAD INVENTORY DATA [Av. size in kg]%%%
% Load average weight data in live weight equivalent (LWE)
% Tables E2.6-E6.11 in Appendix E

W_f = 0.9;     % Includes a 10% additional size reduction

B_09 = importdata('Behold_2009.txt');
B_10 = importdata('Behold_2010.txt');
B_11 = importdata('Behold_2011.txt');
B_12 = importdata('Behold_2012.txt');
B_13 = importdata('Behold_2013.txt');
B_14 = importdata('Behold_2014.txt');
B_15 = importdata('Behold_2015.txt');
B_16 = importdata('Behold_2016.txt');
B_17 = importdata('Behold_2017.txt');
B_18 = importdata('Behold_2018.txt');
B_19 = importdata('Behold_2019.txt');

% Put all inventory data in a 24x72 matrix
B_all = [B_09, B_10, B_11, B_12, B_13,...
           B_14,B_15, B_16, B_17, B_18, B_19]*W_f;

%%%CALCULATE TOTAL BIOMASS LOSS%%%
% Estimated biomass lost [tonnes]
Bio = L_all.*B_all;

% Divide biomass loss into different salmon cohorts
Bio_old = Bio(1:8,:);
Bio_1yr = Bio(9:16,:);
Bio_0yr = Bio(17:24,:);
Bio_all_cohorts = Bio_old + Bio_1yr + Bio_0yr;

% Summing for all counties, divided into cohorts
SUM_Bio_old = sum(Bio_old);
SUM_Bio_1yr = sum(Bio_1yr);
SUM_Bio_0yr = sum(Bio_0yr);

% Summing over all months for years
Bio_old_yr    = [sum(SUM_Bio_old(1:12)) sum(SUM_Bio_old(13:24)) sum(SUM_Bio_old(25:36)) ...
    sum(SUM_Bio_old(37:48))...
            sum(SUM_Bio_old(49:60)) sum(SUM_Bio_old(61:72)) sum(SUM_Bio_old(73:84)) sum( ...
    SUM_Bio_old(85:96))...
            sum(SUM_Bio_old(97:108)) sum(SUM_Bio_old(109:120)) sum(SUM_Bio_old(121:132))...
    ];

Bio_1yr_yr = [sum(SUM_Bio_1yr(1:12)) sum(SUM_Bio_1yr(13:24)) sum(SUM_Bio_1yr(25:36)) sum( ...
    SUM_Bio_1yr(37:48))...
            sum(SUM_Bio_1yr(49:60)) sum(SUM_Bio_1yr(61:72)) sum(SUM_Bio_1yr(73:84)) sum( ...
    SUM_Bio_1yr(85:96))...
            sum(SUM_Bio_1yr(97:108)) sum(SUM_Bio_1yr(109:120)) sum(SUM_Bio_1yr(121:132))...
    ];

Bio_0yr_yr = [sum(SUM_Bio_0yr(1:12)) sum(SUM_Bio_0yr(13:24)) sum(SUM_Bio_0yr(25:36)) sum( ...
    SUM_Bio_0yr(37:48))...
            sum(SUM_Bio_0yr(49:60)) sum(SUM_Bio_0yr(61:72)) sum(SUM_Bio_0yr(73:84)) sum( ...
    SUM_Bio_0yr(85:96))...
            sum(SUM_Bio_0yr(97:108)) sum(SUM_Bio_0yr(109:120)) sum(SUM_Bio_0yr(121:132))...
    ];

% Divide biomass loss into regions
Bio_North = Bio_all_cohorts(1:3,:);
Bio_Cent  = Bio_all_cohorts(4:5,:);
Bio_South = Bio_all_cohorts(6:8,:);

%%%LOAD SEA CAGE DATA AND CALCULATE AVG. LOSS PER CAGE AND LOCALITY%%%
CAGE = importdata('CAGE.txt');
LOC = importdata('LOC.txt');

% Calculate average loss of biomass per cage & locations in regions
AV_CAGE = zeros(8,132);
AV_LOC  = zeros(8,132);

for i = 1:8
```

```
    for j = 1:132
        AV_CAGE(i,j) = Bio_all_cohorts(i,j)/CAGE(i,j);
        AV_LOC(i,j)  = Bio_all_cohorts(i,j)/LOC(i,j);
    end
end

% Divide Av. cages into regions
CA_North = AV_CAGE(1:3,:);
CA_Cent  = AV_CAGE(4:5,:);
CA_South = AV_CAGE(6:8,:);

% Divide location loss into regions
LO_North = AV_LOC(1:3,:);
LO_Cent  = AV_LOC(4:5,:);
LO_South = AV_LOC(6:8,:);

%%%PLOTS%%%
x = 2009:1:2019;     % Yearly distributions
t = 1:132;          % Monthly distributions

% % Cohort distribution of biomass loss
figure
plot(x,Bio_old_yr,'-.o',x,Bio_1yr_yr,'-.x',x,Bio_0yr_yr...
    ,'-.*',x,Bio_old_yr+Bio_1yr_yr+Bio_0yr_yr,'-.s')
xlabel('Timeline')
ylabel('Dead salmon biomass loss [tonnes]')
yticks(10000:10000:120000)
yticklabels({'10 000','20 000','30 000','40 000','50 000','60 000','70 000',...
    '80 000','90 000','100 000','110 000','120 000','FontSize',18})
legend('1> yr cohorts','1 yr cohort','0 yr cohort','Total yearly biomass loss')

% 1 yr cohort average weight and individual losses
figure
L_1yr = L_all(9:16,:);
SUM_L_1yr = sum(L_1yr);

yyaxis right
bar(t,SUM_L_1yr)
hold on
% plot(t,SUM_Bio_1yr)
% hold on
% plot(t,SUM_L_1yr,'-o')

ylabel('Individual salmon dead [1000 pc.]')
box off
grid on
xticks([1 12 24 36 48 60 72 84 96 108 120 132])
xticklabels({'01.09','12.09', '12.10', '12.11', '12.12', '12.13',...
      '12.14', '12.15', '12.16', '12.17', '12.18', '12.19'})

yyaxis left
plot (t,sum(B_all(9:16,:))*(10/9)./8, 'LineWidth',2);
ylim([0 4.5])
ylabel('National average weight of 1 yr cohort [kg]')
xlabel('Month.Year')

% Biomass loss distributed into regions
figure % Northern Norwegian counties
subplot(2,1,1);
plot(t,CA_North)
ylim([0 11])
xticks([1 12 24 36 48 60 72 84 96 108 120 132])
xticklabels({'01.09','12.09', '12.10', '12.11', '12.12', '12.13',...
      '12.14', '12.15', '12.16', '12.17', '12.18', '12.19'})
legend('Finnmark','Troms','Nordland')
title('Average biomass lost per production cage [tonnes]')

subplot(2,1,2);
plot(t,LO_North)
ylim([0 50])
xticks([1 12 24 36 48 60 72 84 96 108 120 132])
xticklabels({'01.09','12.09', '12.10', '12.11', '12.12', '12.13',...
      '12.14', '12.15', '12.16', '12.17', '12.18', '12.19'})
legend('Finnmark','Troms','Nordland')
title('Average biomass lost per locality [tonnes]')

figure %Central Norwegian counties
subplot(2,1,1);
plot(t,CA_Cent)
ylim([0 11])
xticks([1 12 24 36 48 60 72 84 96 108 120 132])
xticklabels({'01.09','12.09', '12.10', '12.11', '12.12', '12.13',...
      '12.14', '12.15', '12.16', '12.17', '12.18', '12.19'})
legend('Tr{\o}ndelag','M{\o}re og Romsdal')
title('Average biomass lost per production cage [tonnes]')

subplot(2,1,2);
plot(t,LO_Cent)
ylim([0 50])
xticks([1 12 24 36 48 60 72 84 96 108 120 132])
xticklabels({'01.09','12.09', '12.10', '12.11', '12.12', '12.13',...
      '12.14', '12.15', '12.16', '12.17', '12.18', '12.19'})
legend('Tr{\o}ndelag','M{\o}re og Romsdal')
title('Average biomass lost per locality [tonnes]')

figure %Southern Norwegian counties
subplot(2,1,1);
plot(t,CA_South)
ylim([0 11])
```

```
xticks([1 12 24 36 48 60 72 84 96 108 120 132])
xticklabels({'01.09','12.09', '12.10', '12.11', '12.12', '12.13',...
     '12.14', '12.15', '12.16', '12.17', '12.18', '12.19'})
legend('Sogn og Fjordane','Hordaland','Rogaland og Agder')
title('Average biomass lost per production cage [tonnes]')

subplot(2,1,2);
plot(t,LO_South)
ylim([0 50])
xticks([1 12 24 36 48 60 72 84 96 108 120 132])
xticklabels({'01.09','12.09', '12.10', '12.11', '12.12', '12.13',...
     '12.14', '12.15', '12.16', '12.17', '12.18', '12.19'})
legend('Sogn og Fjordane','Hordaland','Rogaland og Agder')
title('Average biomass lost per locality [tonnes]')
```

Matlab code G2: Boxplots

```
close all;
clear all;

%%%LOAD LOSS DATA%%%
% Tables E1.1-E1.11 in Appendix E.
L_09 = importdata('Loss_2009.txt');
L_10 = importdata('Loss_2010.txt');
L_11 = importdata('Loss_2011.txt');
L_12 = importdata('Loss_2012.txt');
L_13 = importdata('Loss_2013.txt');
L_14 = importdata('Loss_2014.txt');
L_15 = importdata('Loss_2015.txt');
L_16 = importdata('Loss_2016.txt');
L_17 = importdata('Loss_2017.txt');
L_18 = importdata('Loss_2018.txt');
L_19 = importdata('Loss_2019.txt');

% Put all loss data in a 24x120 matrix
L_all = [L_09, L_10, L_11, L_12, L_13,...
            L_14, L_15, L_16, L_17, L_18, L_19];

%%%LOAD INVENTORY DATA [Av. size in kg]%%%
% Load average weight data in live weight equivalent (LWE)
% Tables E2.6-E6.11 in Appendix E

W_f = 0.9;     % Includes a 10% additional size reduction

B_09 = importdata('Behold_2009.txt');
B_10 = importdata('Behold_2010.txt');
B_11 = importdata('Behold_2011.txt');
B_12 = importdata('Behold_2012.txt');
B_13 = importdata('Behold_2013.txt');
B_14 = importdata('Behold_2014.txt');
B_15 = importdata('Behold_2015.txt');
B_16 = importdata('Behold_2016.txt');
B_17 = importdata('Behold_2017.txt');
B_18 = importdata('Behold_2018.txt');
B_19 = importdata('Behold_2019.txt');

% Put all inventory data in a 24x72 matrix
B_all = [B_09, B_10, B_11, B_12, B_13,...
            B_14,B_15, B_16, B_17, B_18, B_19]*W_f;

%%%CALCULATE TOTAL BIOMASS LOSS%%%
% Estimated biomass lost [tonnes]

Bio = zeros(24,132);

for i = 1:24
    for j = 1:132
        Bio(i,j) = L_all(i,j)*B_all(i,j);
    end
end

% Divide biomass loss into different salmon cohorts
Bio_old = Bio(1:8,:);
Bio_1yr = Bio(9:16,:);
Bio_0yr = Bio(17:24,:);
Bio_all_cohorts = Bio_old + Bio_1yr + Bio_0yr;

%%%LOAD SEA LOCALITY DATA AND CALCULATE AVG. LOSS PER LOCALITY%%%
LOC = importdata('LOC.txt');

AV_LOC = zeros(8,132);

for i = 1:8
    for j = 1:132
        AV_LOC(i,j)  = Bio_all_cohorts(i,j)/LOC(i,j);
    end
end

AV_LOC = transpose(AV_LOC);

% Creating one 12x11 matrix for each county
AV_FINN = AV_LOC(:,1); AV_TROM = AV_LOC(:,2); AV_NORD = AV_LOC(:,3);
```

```
AV_TRON = AV_LOC(:,4); AV_MORO = AV_LOC(:,5); AV_SOFJ = AV_LOC(:,6);
AV_HORD = AV_LOC(:,7); AV_ROAG = AV_LOC(:,8);

%AV_FINN2 = zeros(12,11);
k = [1:12:132 133];
for i = 1:11
        AV_FINN2(:,i) = AV_FINN(k(i):k(i+1)-1);
        AV_TROM2(:,i) = AV_TROM(k(i):k(i+1)-1);
        AV_NORD2(:,i) = AV_NORD(k(i):k(i+1)-1);
        AV_TRON2(:,i) = AV_TRON(k(i):k(i+1)-1);
        AV_MORO2(:,i) = AV_MORO(k(i):k(i+1)-1);
        AV_SOFJ2(:,i) = AV_SOFJ(k(i):k(i+1)-1);
        AV_HORD2(:,i) = AV_HORD(k(i):k(i+1)-1);
        AV_ROAG2(:,i) = AV_ROAG(k(i):k(i+1)-1);

end



% %%%BOXPLOTS%%%
x = 2009:1:2019;    % Yearly distributions

figure % Finnmark
boxplot(AV_FINN2,x)
ylim([0 45])
ylabel('Mean monthly biomass loss per locality [tonnes]')
title('Finnmark')

figure % Troms
boxplot(AV_TROM2,x)
ylim([0 45])
ylabel('Mean monthly biomass loss per locality [tonnes]')
title('Troms')

figure % Nordland
boxplot(AV_NORD2,x)
ylim([0 45])
ylabel('Mean monthly biomass loss per locality [tonnes]')
title('Nordland')

figure % Tr{\o}ndelag
boxplot(AV_TRON2,x)
ylim([0 45])
ylabel('Mean monthly biomass loss per locality [tonnes]')
title('Tr{\o}ndelag')

figure % M{\o}re \& Romsdal
boxplot(AV_MORO2,x)
ylim([0 45])
ylabel('Mean monthly biomass loss per locality [tonnes]')
title('M{\o}re & Romsdal')

figure % Sogn \& Fjordane
boxplot(AV_SOFJ2,x)
ylim([0 45])
ylabel('Mean monthly biomass loss per locality [tonnes]')
title('Sogn & Fjordane')

figure % Hordaland
boxplot(AV_HORD2,x)
ylim([0 45])
ylabel('Mean monthly biomass loss per locality [tonnes]')
title('Hordaland')

figure % Rogaland \& Agder
boxplot(AV_ROAG2,x)
ylim([0 45])
ylabel('Mean monthly biomass loss per locality [tonnes]')
title('Rogaland og Agder')
```