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Salmon smolt outmigration surveillance: a comparison of methods and an analysis of the Traffic Light System

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Abstract

The salmon aquaculture industry has grown into one of the most vital industries in Norway, but its quick expansion has led to several environmental challenges, in particular the threat of salmon lice to wild salmon populations. This threat has acted as the environmental indicator for the basis of the Traffic Light System, a regulatory system which is the result of years of public policy. This thesis aims to compare three different data collection methods for monitoring the outmigration of salmon smolts and how the results from these collection methods inform government decisions. It also seeks to evaluate the effectiveness of the Traffic Light System. Thematic document analysis and literature review are used for a theoretical comparison of the data collection methods and for evaluation of the Traffic Light System. The data collection methods compared are Acoustic Telemetry, Passive Integrated Transponder (PIT) and Camera recordings. The results suggest that between PIT and Camera, PIT is about twice as reliable as cameras, though both methods have their advantages and limitations. Out of these methods, Acoustic Telemetry appears to result in a more accurate data collection method between the three. The short period of time that the Traffic Light System has been implemented makes it difficult to evaluate how effective it is, but the system does provide indirect financial and reputational incentives for companies to keep lice infestations to a minimum. Migration timing is one of the vital input variables for models that form the scientific basis for the recommendations to the Ministry of Trade, Industry and Fisheries regarding the Traffic Light System, but migration timing remains a sensitive and uncertain parameter. Ultimately, and although there is a degree of uncertainty regarding a vital parameter in these models, the Traffic Light System is indicative of the start of an increasingly sustainable industry.

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1. Introduction

According to Thorstad et al. (2012), Atlantic salmon (Salmo salar) “is a species of biological, cultural and economic importance”, spending their juvenile years in freshwater and later migrating to sea. During the last 45 years, the salmon aquaculture industry has grown into one of the most vital industries in Norway, valued in 2017 at more than 61 billion NOK (SSB, 2018), a world leader in production and export (Olfasen et al., 2012). In 2012, the production of Atlantic Salmon reached 1.232.095 tons, in a total of more than 1000 farms. The quick expansion of the industry has led to several environmental challenges (Taranger et al., 2015), becoming a threat to wild salmon (Tiller et al., 2017). And in 2017, production reached more than 1.236.354 tons (SSB, 2019). To cope with the rapid expansion of the industry and the environmental challenges it presents, the Norwegian Government decided to introduce the Traffic Light System (TLS), which is a system meant to regulate the growth of the salmon farming industry, dividing the Norwegian coastal production area into 13 production areas (Anon., 2015).

While there are several major threats to Atlantic salmon, this research project chooses to focus on salmon lice (*Lepeophtheirus salmonis*), which feed on fish’ mucus, skin, and muscle (Thorstad and Finstad, 2018), and on the methods used to study timing migration in Atlantic salmon smolts. Sea lice level is currently the only indicator used in the TLS, and the impact that it has on the wild salmon population might cause a production area to be classified into green, yellow or red. A red classification can have a large economic impact, as companies operating within the area must reduce their annual production by 6% (Bjørnar, 2019).

This study will compare the different data collection methods that are used to monitor the outmigration of salmon smolts, and how the results from these different methods inform government decisions. It will also specifically evaluate the impact the TLS has, and whether it is effective at regulating the production in the salmon aquaculture industry to an extent that it is beneficial to the environment and the wild salmon populations it tries to protect.

However, before delving into the data collection methods and the data analyzed, background information on Atlantic salmon (*Salmo salar)*, salmon lice (*Lepeophtheirus salmonis),* and the TLS will be given. This will be in order to provide an understanding of the complexity of not only the advantages and disadvantages of using different collection methods for outmigration surveillance, but also the vulnerability of the wild Atlantic salmon species, the threat that salmon lice pose, and the delicate balance between society and environment.

2. Atlantic salmon

a. Lifecycle

Atlantic salmon *(Salmon salar)* (Fig. 1) spend their life as juveniles in freshwater. They might spend one year to almost a decade in that environment (normally 2-3 years in Norway), before migrating to sea, being referred to as smolts during their migrating stage in freshwaters, and post-smolts as soon as they enter the sea (Thorstad, E.B. & Finstad, B. 2018; Thorstad et al. 2010).

Figure 1. Wild Atlantic Salmon (Vitenskapelig råd for lakseforvaltning, 2019)

Atlantic salmon's life cycle consists of spawning in fresh water and migrating to the sea, a food rich environment, where they have more growth opportunities (Gross et al. 1988; Jones, 1998; Klemetssen et al. 2003). This migration is an adaptation that allows individuals to use the best suited habitat for each different life stage in an attempt to increase individual fitness and offspring survival (Thorstad et al. 2012).

Mortality in wild salmon due to salmon lice normally happens in their post-smolt phase as they enter the sea, swimming through coastal waters, while on their way to ocean feeding areas. Lethal levels are considered to be 11 mobile lice per 15 g wild salmon (Thorstad and Finstad. 2018). These lethal levels are based on laboratory studies but rely on field observations, where out of 3000 wild salmon sampled, none were found carrying more than 10 adult salmon lice (Holst et al. 2003). Mortality happens because of skin lesions and damaged fins caused by the sea lice, which reduce swimming performance and alter the behavior of fish, and it occurs within 10 to 20 days of exposure in the greatly infested fish. These damages lead to diminished immune resistance as well as problems with salt regulation, growth and life expectancy (Thorstad and Finstad. 2018).

An annual loss of 50.000 adult, wild Atlantic salmon in Norwegian rivers, approximately 10% of the population, is caused by salmon lice, based on data collected from 2010 to 2014. (Forseth et al. 2017). The harm caused by salmon lice's booming population originating the farming industry, and its impact on wild salmon, has been a topic of conversation for years.

In 2001, Bjørn et al. (2001), pointed out that the transmission of sea lice from farmed to wild salmon may have negative environmental effects. Furthermore, a substantial amount of the total costs of farmed salmon production is used on control of infestation and assessments of sea lice (Iversen et al., 2013). Strategies "such as spatial segregation of farmed fish and lice or moving farms away from vulnerable habitats" could ensure a more sustainable practice (Bøhn et al., 2020).

Regarding environment-specific mortality of smolts, Thorstad et al. (2012) found that estuaries and river mouths have the highest mortality rates of migration smolts, mostly due to predation by birds, mammals, and other fishes.

Other major threats to Atlantic salmon are hydropower and migration barriers, diseases, pollution, climate change, and genetic introgression. Many of these factors can be further classified into factors affecting population to the extent of critically endangering them, factors that contribute to critically endangering the population, factors that cause a reduction of returning adults and threaten populations, and factors that cause a reduction of returning adults but not to the extent of threatening the population (Forseth et al., 2017).

b. Smoltification

Before migrating to the sea, the fish must undergo smoltification to withstand high salinity environments, which involves "morphological, biochemical, physiological and behavioural changes" (Thorstad et al., 2012; Hoar, 1988; Thorpe et al., 1998; Finstad & Jonsson, 2001), which are represented in Table 1. The smolting process is triggered by an increase in day length and changes in water temperature (McCormick et al., 1987; McCormick et al., 1998).

The morphological changes also help the fish blend with their new environment (Thorstad et al. 2012).

Table 1. Overview of changes that occur during the smolting process.

Smolting process changes			
Morphological	**Biochemical**	**Physiological**	**Behavioural**
• Slimmer body • Change in body colouration (dark fins, dark back, white belly, silver sides) • High growth rate	• Changes in plasma ion concentrations • Increases in gill Na^+K^+ATPase activity, thyroid hormones, growth hormone (GH), cortisol and insulin-like growth factor-I	• Active regulation of body salt concentrations in a hyperosmotic environment	• Loss of territoriality • Inhibition of positive rheotaxis • Adoption of schooling behaviour

(Thorstad et al. 2012).

c. Migration (timing)

The smolts’ behaviour and survival during migration can be affected by many factors, such as pollution, fish farming, sea lice, hydropower developments or other human activities that can cause death, delay migration, or inhibit it (Thorstad et al. 2012). The timing of smolt migration also plays a role on whether the salmon will survive, and this timing varies depending on the location of the river. This is most likely due to local adaptations in the population, ensuring optimal conditions at the moment of entry into the sea (Thorstad et al. 2012).

Migration occurs during the spring and early summer, usually triggered by one or more environmental factors that the smolts experience, indicative of conditions at sea. Most of the individuals of a population migrate within a period of 1-2 weeks (McCormick et al., 1998; Riley et al., 2002; Thorstad et al. 2012), although recent evidence suggests migration to be multimodal over a period of about 4 to 6 weeks (Urke at al., 2018; Bjerck et al., 2021). Downstream migration is caused mostly by increased water discharge and water temperature, though the effects of these may vary depending on the population, with migration being initiated solely by one of these two factors in some rivers (Jonsson & Rudd-Hansen, 1985; Carlsen et al. 2004; Davidsen et al., 2005; Thorstad et al. 2012). The preference for specific water temperatures may be due to the fact that, at low temperatures, smolts have low salinity tolerance, thus increasing mortality (Sigholt & Finstad, 1990). Increased chances of survival at higher water temperatures may be linked to increased prey stock and increased swimming performance (Thorstad et al. 2012)

Social cues can also be a factor of migration, by the presence of other migrants in the environment (Hansen & Jonsson, 1985; Hvidsten et al., 1995). McCormick et al. (1998) states that for smolt survival in the marine environment, the timing of migration is crucial. Norwegian salmon smolts enter the sea at different times of the season, during darker hours of the day (Hvidsten et al., 1998, 2009; Haralstad et al., 2017). This would mean that smolts in southern waters would migrate earlier than those in northern waters (Thorstad et al. 2012). Variations in timing within populations may occur to reach the ocean at a favorable time in order to grow and survive (Hvidsten et al., 2009). Yearly variations in migration from the same river may be caused by environmental differences year-by year, with perhaps an unusually cold winter and spring resulting in delayed smolt migration (Hulbak, 2020). A deeper understanding of the variation in migration is crucial if we are to understand the impact salmon lice and climate change will have on wild Atlantic salmon (Bjerck et al. 2021).

For the survival of Atlantic salmon, especially during times of high salmon lice density, timing of their migration could mean the difference between life or death. Mortality risk during sea migration can be 50 times higher when there is high lice density, even in areas that are protected (Bøhn et al., 2020). Early migrating fish have a much higher chance of survival from sea lice (Kristoffersen et al., 2018), due to the seasonal variation in lice populations. During times of high lice infestation, mortality can be close to 100% (Bøhn et al., 2020). Their migration pattern can also be interpreted as adaptations in trying to avoid predation (Haralstad et al., 2017). Salmon populations with a long fjord migration experience lower survival rate than those who have a short migration into the sea (Bjerck et al. 2021). Finstad & Jonsson (2001) found that synchronous migration can be evidence of an antipredator behaviour displayed by the salmon to increase their likelihood of survival, by confusing or swamping the predator.

3. Salmon lice

The salmon lice (*Lepeophtheirus salmonis)* life cycle (Fig. 2) is made up of three planktonic larval stages that originate from two egg strings which the adult female produces. These life stages consist of two naupliar stages where infection is not possible and one infective copepodid stage, in addition to two chalimus and pre adult stages, and the adult stage (Hamre, 2013; Thorstad and Finstad, 2018).

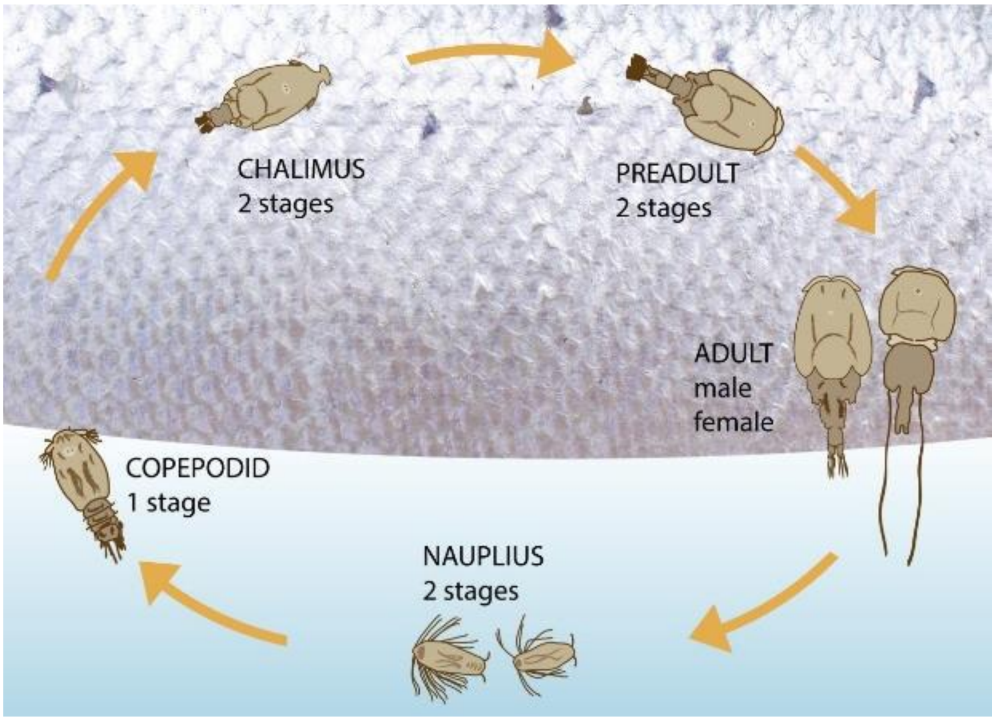

Figure 2. Life cycle of salmon lice (Thorstad and Finstad, 2018).

Salmon lice feed on fish's mucus, skin, and muscle (Thorstad and Finstad, 2018). Water temperature acts as an essential regulator in the development times of lice throughout their life cycle and is particularly important during their non-feeding planktonic stage. In warmer waters they develop faster towards their infectious stage but consume their energy quicker than in colder temperatures, making them viable for a shorter time frame (Johnson and Albright, 1991; Pike and Wadsworth, 1999; Tucker et al. 2000).

Although they are viable for a shorter time frame, their quick development in warmer waters, together with increasing ocean temperatures due to climate change, could mean that salmon lice have the possibility to become an even bigger threat in the future. Samsing et al. (2016) seem to reach this conclusion, stating "low temperatures have a more detrimental effect on salmon lice survival and infectivity than high temperature". This argument actively illustrates, at least in part, the reasons why there is a lower occurrence of salmon lice in Northern Norway, in comparison to other parts of Norway, a fact that could also change if a lice population were to adapt to colder waters. Thorstad et al. (2012) reaffirms the danger of increasing ocean temperatures by noting that sea-lice in coastal areas increases with higher temperatures, thus higher temperatures may increase the abundance of sea-lice per year. However, climate change also means an increase in precipitation, and according to Mohn et al. (2020), low-salinity surface water also decreases the number of lice.

Climate change has already affected Atlantic salmon and will continue to affect the species. The southern and western regions of Norway will continue to deal with the impact of salmon lice, though it is already great. In northern Norway, climate change may actually aid in increasing salmon production (Forseth et al., 2017). However, Bøhn et al. (2020) point out that the asynchronous shifts that may be caused by climate change in the timing of both smolt migration and lice blooms would have unknown consequences. Otero et al. (2014) also highlights that northern populations have already exhibited earlier migration, associated with climate change, over time.

For salmon lice, host fishes include Atlantic salmon (*Salmo salar),* sea trout *(Salmo trutta),* and Arctic char *(Salvelinus alpinus),* with successful infestation and settlement taking part in three different phases. These phases are initial attachment, followed by exploration, ending with fixation to the host (Froese and Pauly, 2009; Bron et al. 1991). All three phases need energy, with the final phase ending with the production of a frontal filament that attaches the larvae to the host, causing energy depletion in the non-infectious stages which can result in a lack of infectivity (Pike et al. 1993; Tucker et al. 2000).

Salmon lice may also cause dysfunctional osmoregulation, physiological stress responses, a deficiency in the number of red blood cells, increased likelihood of microbial infections, and increased mortality, especially due to the problems in balancing salt levels, caused by sea lice (Thorstad and Finstad, 2018). Both physical damage to the skin and the physiological stress responses caused by the salmon lice are damaging factors of osmoregulation in Atlantic Salmon (Thorstad et al. 2015).

Furthermore, Torrissen et al. (2013) highlights that intensive salmon farming, which has increased in the last decades, produces ideal conditions for parasite proliferation as opposed to a natural habitat. This causes issues for both the salmon aquaculture industry and, to an extent, wild salmonids. In farmed areas that have synchronized production cycles, the correlation between salmon farming and lice production is even more evident (Butler, 2002; Revie et al. 2002, Gillibrand et al. 2005, Harte et al. 2017). According to Taranger et al. (2014), more than a billion salmon lice larvae are released daily from salmon farms in Norway. To further complicate the situation, elevated salmon lice levels can lead to the lack of enough spawners in order to reach the conservation limits that have been set (Thorstad and Finstad, 2018). This would not only affect fisheries, but it would also cause reduced wild stocks and affect fishermen who benefit from wild salmon. In Hardangerfjorden, for example, the amount of returning fish from rivers further away from the coast is lower than those closer to the coast, perhaps in relation to lice exposure time or predation (Vollset et al., 2014).

As the environmental impact of the industry is an important aspect, production increases have not been easily allowed (Brakstad et al., 2019). In addition, all farming sites deliver a weekly report on the amount of sea lice in the fish (Taranger et al., 2015), presumably to maintain a thorough record and overview of the infestations, as fish farms have a set limit of below 0.2 adult female lice per salmon during migration (spring) and 0.5 adult female lice per salmon the rest of the year (Bøhn et al., 2020).

4. Traffic Light System

There is no doubt that the salmon farming industry has been beneficial for Norway’s economy. Yet the industry, not without its faults, depends on public perception and the belief that government agencies can control such industry. It also needs to appear trustworthy, to access resources and be able to grow and develop through beneficial regulations (Tiller et al., 2017). In order to study the TLS, which is a regulatory system for production in the salmon aquaculture industry, one needs to study the relationship between environment and society, as this is key to maintaining the system.

However, first we must acknowledge that the environment is, above all, a political space, which gains meaning through representational practices and technologies. Environmental politics is thus not a product of nature, but of representational practices. To then operate effective regimes, it is a necessity to know about environmental problems and the possible response options, but this is not sufficient for the operation of the regime. In order to shape policy, a careful balancing act must be performed, with scientific integrity on the one hand, and policy involvement and receptiveness on the other (Lövbrand, 2014).

Environmental sociology studies the relationship between environment and society, a key point to maintaining the TLS, but we also need to acknowledge that they cannot be understood as distinct from each other, given that environmental issues are socially constructed in order to be understood and find strategies to battle them. Of course, they are also the result of ecosystem processes, and we gain knowledge of them through science and technology. This shift in thinking allows us to move from the symbolism of environmental issues to their causes, consequences, and our ability to change them. It also allows us to observe and study the links between people, institutions, technologies, and ecosystems (Lockie, 2015).

This is not to say that the research done, and problems analyzed for this paper, are entirely sociological. However, if one is to improve on the TLS, it needs to be acknowledged that the basis for this system is biological and ecological, the issues it tries to deal with are environmental, but ultimately it is a sociological conundrum. As Lockie (2015) points out, biology and ecology are deeply entrenched in the social realm. The TLS could also be classified as a ‘wicked problem’, given that it follows most characteristics associated with what makes a wicked problem, such as having no definitive solution or not true solution, the problem it tries to tackle has been contested, it is essentially unique, and there is little to no public tolerance to failures in the area (Head, 2008).

In the end, this regulatory system is the result of public policy, which according to Howlett (2014), is used as a way of altering behavior in order to accomplish a specific target. It is important to note that a system with the magnitude such as the TLS to regulate an industry as vital as fish farming was not done lightly. In fact, a thorough process, expanding over several years, was done to make sure it was implemented the right way.

In the representation of the TLS (Fig. 3), three hearing processes and two documents have been included, which are:

- A hearing on the report on efficient and sustainable area use in the aquaculture industry (The Norwegian Government, 2011).
- The White Paper nr. 16 2014-2015: Predictable and environmentally sustainable growth in Norwegian salmon and trout farming (MTIF, 2015).
- A hearing on the report to Parliament on growth in Norwegian salmon and trout farming (The Norwegian Government, 2018a).
- A report on the efficient and sustainable area use in the aquaculture industry – area for desire (Gullestad et al., 2011).
- A hearing on the proposal for regulations to implement a new system for capacity adjustments in salmon and trout farming (The Norwegian Government, 2018b).

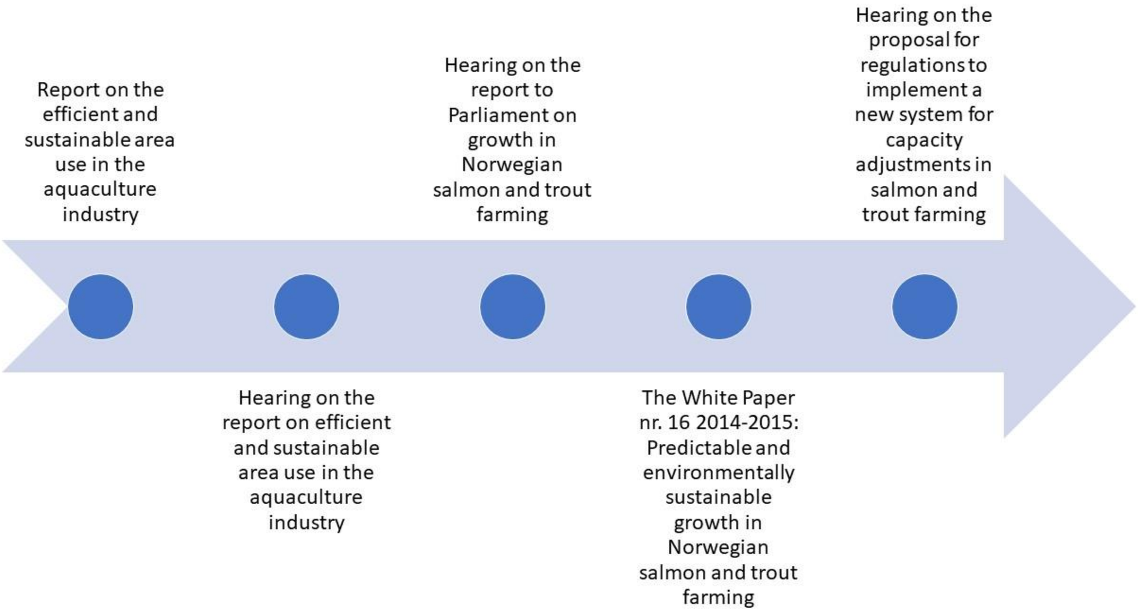

Figure 3. Process of implementation of the Traffic Light System with hearings and documents in chronological order.

A total of seven hearings analyzed the possibility of the TLS. From the process represented above, four hearings have been removed. One of the hearings occurred after the implementation of the system, such that is not relevant for the representation of the implementation itself. A second and third hearing were removed because they dealt with land-based aquaculture and the Aquaculture fund, which are not relevant for this particular research. A fourth hearing regarded licenses across production zones, which is a specific aspect of the TLS but does not cover the implementation of the system itself, which is why it has been removed (Bjørnar, 2019).

a. Background of the TLS

The Traffic Light System, or TLS, originated from a White Paper presented in 2015 where the Norwegian government proposed a system meant to regulate the growth of the salmon farming industry, in efforts to not only add predictability but to also be environmentally sustainable, representing a significant change in how the industry was managed. It officially began on October 30th, 2017 (Anon., 2015; Bjørnar, 2019). In their effort for environmental sustainability, the Government issued a press release stating that “environmental impact should be the most important assessment criterion” regarding the operation and production of the industry (Anon., 2015). But what does it mean to be environmentally sustainable? In order to eliminate the vagueness of the term, sustainability needs to be properly defined within a framework of environmental indicators that include a level of tolerance and risk, and the consequence of certain levels (Bailey & Eggereide, 2020) When it comes to environmental indicators, it was eventually concluded that from the risks of genetic interaction with escapees, pollution, diseases, parasites, and harvesting of feed resources, sea lice (the parasite) was the only possible indicator in the short- and mid-term (Anon., 2015).

The selection of this indicator has grounds in previous policy, and using indicators in order to inform policy decisions is a common approach in the field of natural resources management (Bailey & Eggereide, 2020). As such, the variability of sea lice concentration in the production zones which are overseen by the TLS will depend on the number of lice that is released by fish farms, the location of the farms, and the dynamic of currents and water distribution in a specific zone (Myksvoll et al., 2020). The impact salmon lice have on the wild stock is the only direct, measurable indicator that can be linked to salmon farming in the sea (Bjørnar, 2019), and this parasite also has considerable economic costs for the salmon industry, both because of the ways to deal with it, and due to harm to the public image of the industry as a whole (Torrissen et al., 2013). We also know that indicators can be chosen for different reasons, which may be grounded in science or in cost effectiveness (Bailey & Eggereide, 2020).

Several models have been created to calculate and summarise lice-induced mortaliy in Norwegian waters. These models take into account migration timing of salmon smolts, the time postsmolts spend in fjords, and lice pressure. In turn, the models have an important role in the creation of a regulated system for the aquaculture industry (Taranger et al., 2015; Vollset et al. 2017; Nilsen et al., 2017).

The idea behind the Traffic Light System is predictability, laying the ground for decisions that are made through a transparent system that influences production capacity, knowing which criteria must be achieved for growth to occur, and knowing the consequences of unacceptable or moderate environmental impact. (Anon., 2015). The colour-coded impact categories (green, yellow, red) are based on a single indicator, the effect of lice in wild salmon, or the likelihood of wild salmon dying because of it (sea-lice induced mortality). Green represents 0%-10% impact, yellow 10%-30% impact, and red more than 30% impact. Green means the chance to increase maximum permitted production volume by up to 6%, yellow means there is no allowed increase in maximum permitted production volume, red means the company must decrease their production volume by 6% (Bøhn et al., 2020). In order to divide and administers the 13 production zones (Fig. 4), the governance regime uses a tripartite (three-party) coalition system composed of regional, national and municipal governments, where municipalities have the primary responsibility for projects along the coast, making cooperation between the levels of government essential in order for the system to work (Tiller et al., 2017).

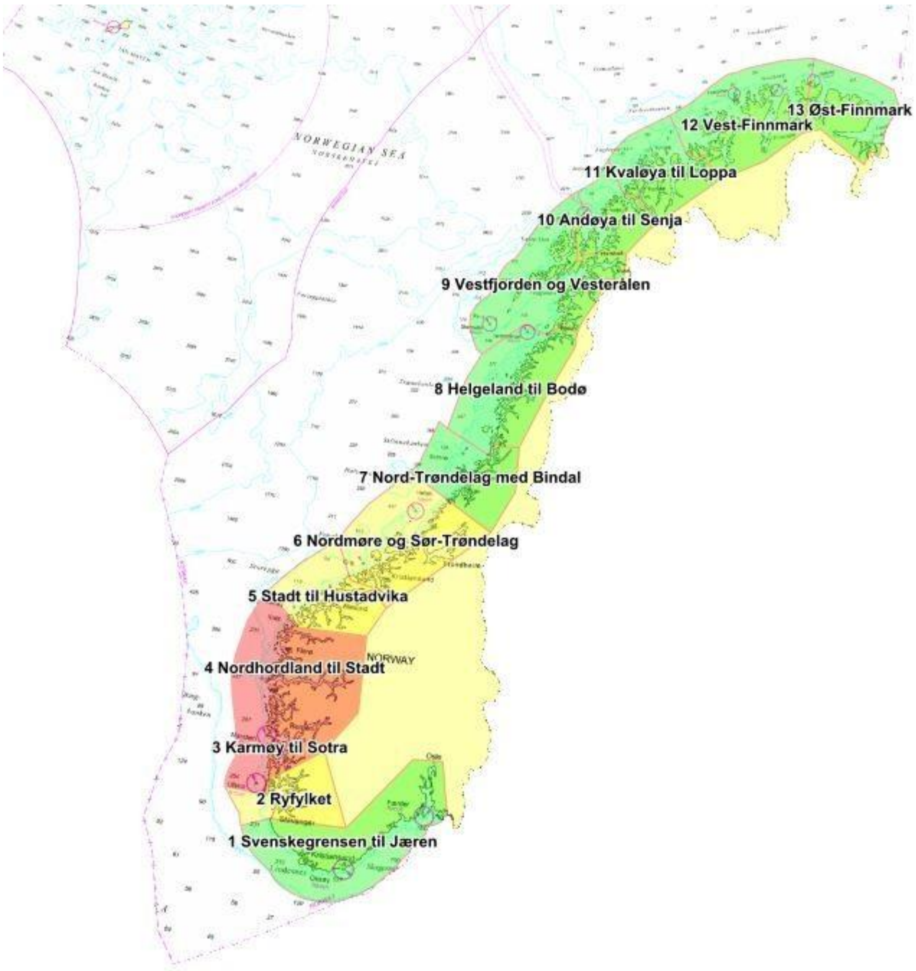

Figure 4. Norway’s traffic light aquaculture zones (Stoichevski, 2018).

The choice of production zones was based on several factors. On the Government’s side, their explanation was that “the environmental footprint of each individual site may be acceptable, but the combined footprint from all sites in an area may be unacceptable.” Those zones with an acceptable environmental impact should increase production capacity, those with a moderate impact should keep the same production capacity, and where impact is unacceptable, the production capacity should be reduced. The proposed increase in capacity is 6% every second year (Anon., 2015), reaching an increase of 500% in production by 2050 (Vollset et al., 2017). If this is the goal, then it would lead to the worsening of an already non-sustainable practice based on the wild salmon stock, if no other changes are made to ensure the sustainability of salmon farming, assuming that an increase in fish biomass would also increase the salmon lice released from farms. The production zones are assessed every second year by a team of experts that look at the sea-lice induced mortality in migrating wild salmon, updating the classification of the areas based on the proper criteria and regulating production accordingly (Myksvoll et al., 2020). However, there are two ways companies can avoid halting their production, and even increase it from 0-6%, if they find themselves in a yellow or red zone. They could have a production method that doesn't release sea lice into the open sea or have an open production method where there cannot be more than 0,1 sexually mature female lice per salmon (Bjørnar, 2019).

b. Effectiveness of the TLS

At its core, the TLS is an environmental regime, or governance system, which tend to work well at a national level, though how effective they area at reaching their goals is up for discussion, and it is often hard to measure complete failure or complete success. We can refer to effectiveness as "the extent to which regimes contribute to solving or mitigating the problems that motivate those people who create the regimes" (Young, 2011). It is common for these regimes to not reach their goals, and like the ebb and flow of the ocean, they are dynamic in their effectiveness towards the problem they try to solve, weaking or strengthening with the passage of time. A regime's design may also be linked to their effectiveness, more than the problem they are trying to tackle (Young, 2011). The effectiveness of this governance system may also rely on how well Norway is able to manage the natural resource that is their sea. Luckily, Norway does have a history of natural resource management that smartly integrates industry that are based on natural resources to the rest of the economy, while at the same time creating institutions that can handle economic hardships which are common in resource productions (Cappelen & Mjøset, 2009).

How effective a regime is also depends on context, legitimacy, and fairness, especially when involving private governance or hybrid systems with public and private characteristics (Young, 2011). Their success or failure will be defined based on the perspective that is applied. From a governmental point of view, the TLS is an overall success, given that many of the parameters they wanted in the system, such as production zones and salmon lice as an environmental indicator, became a part of it (Bjørnar, 2019). There have been conscious political decisions in order for the Norwegian government to extensively control the management of this resource. Appropriate management of resources, such as information collection, exploration, and production control, are necessary if one is to reap the economic benefits while still remaining sustainable (Cappelen & Mjøset, 2009). From a production growth view and employment standpoint, the salmon industry is a success story. However, the industry is also prone to the excessive use of resources in the surrounding ecosystem, and their intensive production means that salmon lice proliferate in a greater manner, leading to problems with the wild stock (Torrissen et al., 2013).

c. Reliability and public trust

Governance regimes rely on public trust to function and grow, but growth can be difficult to achieve without trust in regulating the industry, and it is especially important when the industry is crucial to the development of rural areas (Tiller et al., 2017). While Tiller et al. (2017) found that stakeholders value expert opinions highly, that result has not been reflected in the recent lawsuit made by a conglomerate of aquaculture companies which have sued the government over their decision to "turn the red light" in a production area. This lawsuit instead shows that expert opinions are not being valued by this conglomerate (Sogn og Fjordane Tingrett, 2021).

The lawsuit specifically questioned the government's decision on the capacity adjustment of production area 4 (PO4), which required the reduction of maximum permitted production volume by 6%. The companies which had to reduce production instead offered an alternative, which was to reduce production by 12% in volume from April 2021 until August 2021, and increase the equivalent production afterwards, thus shielding the wild salmon during the vulnerable period of migration. However, the expert group in charge of informing the Ministry of Trade, Industry and Fisheries, which makes the ultimate decisions regarding the TLS, decided that the proposal by the companies would lead to a negative impact on both wild salmon and trout. The plaintiffs' claims were that the decision by the Ministry was not binding, that the State was liable to pay compensation to the plaintiffs, and that they should be awarded the costs of the court as well. The court focused on evaluating the decision made by the ministry's assessment, and whether this decision was necessary out of consideration for the environment. The court concluded, even before providing a final verdict, that the "necessity out of consideration for the environment" was at the discretion of the Ministry. It is important to note that the Ministry did not take this decision lightly, and that it considered the socioeconomic implications the decision would have. However, any alternative method besides production volume reduction would not have been sufficient, in their eyes, to protect the wild salmon. In the end, the court ruled in favor of the State (Sogn og Fjordane Tingrett, 2021).

In order to access resources and support for development, the Norwegian aquaculture industry must have a favourable public reputation, and this can prove difficult due to the threat that salmon aquaculture poses to wild salmon and other species (Tiller et al., 2017).

5. Methods

a. Thematic document analysis

One of the three foundations of this thesis is the qualitative analysis in the form of thematic document analysis, which Bowen (2009) defines as “a systematic procedure for reviewing or evaluating documents – both printed and electronic material.” By using this method, one takes advantage of stability and lack of obtrusiveness of document analysis (Bowen, 2009). This has been especially useful when field work has not been as accessible because of the COVID-19 pandemic. Unlike literature review, thematic document analysis relates to reviewing documents with fall outside of the regular scientific literature. In this study, it relates to government documents such as the White Paper nr. 16, government press releases, and documented hearings on the TLS. These documents were analyzed to evaluate the implementation process of the regulatory system for the salmon aquaculture industry. Utilizing documents avoids the bias of other qualitative methods such as interviews, it allows the coverage of a lot of a material in a short time, and it provides a stable source for research that is not altered by one’s own research (Bowen, 2009).

b. Literature review

The second foundation of this thesis is the qualitative analysis in the form of literature review, with a semi-systematic approach. This is the best approach if the topic to be researched has been studied by researchers in various disciplines (Wong et al., 2013). Because this method tries to identify and understand relevant research related to the studied topic, it can provide an understanding of complex areas and how they have progressed over time (Snyder, 2019). In the specific case of this thesis, both social and biological concepts are used to provide a complex comparison of the methods used when monitoring wild salmon smolt migration, and a thorough analysis of the TLS, which acts as the regulatory system for the salmon farming industry. Taken together, it becomes a complex topic that requires a semi-systematic approach regarding the literature to not only understand it but to analyze and detect knowledge gaps within it, possibly providing a historical overview of the topic and a summary of how much we know about the topic that is being discussed (Snyder, 2019).

c. Data collection and analysis

The third and last foundation of this project are the methods of data collection for the outmigration of salmon smolts and data analysis. In this instance, the methods utilized for data collection are acoustic telemetry, PIT (passive integrated transponder) recordings, and camera recordings. The reliability of data collection systems is vital, as it will define the quality of a study. Systems that have a high detection probability are better because they require the tagging of fewer fish to produce the survival estimates with the required precision.

- **PIT,** or "passive integrated transponder" is a type of tag made up on an electronic microchip surrounded by biocompatible glass. They allow the observation of movement, and survivorship in many species, in a reliable manner, as accurate as a fingerprint, providing information on an individual, and populations. The tag is passive because it is not activated until the use of a scanner (Gibbons & Andrews, 2004), using RFID, which stands for "Radio Frequency Identification" and can identify objects, or in this particular use, fish, remotely and through the use of radio frequencies (Biomark, 2019). During recapture, PIT tags can also provide information on growth rate. Furthermore, they can be used along with automatic monitoring systems, thus eliminating the need for recapture. An automated monitoring system with PIT tags, which is used for the monitoring of migration of fish, involves placing one or several readers along the animal's suspected path, allowing for daily activity monitoring (Gibbons & Andrews, 2004). The quality of PIT-based studies relies on fish keeping their tags over the period of the study, without affecting the fish's survival or their behavior (Foldvik & Kvingedal, 2018). In a long-term retention study done by Foldvik & Kvingedal (2018) in indoor fish, lasting over 500 days, they concluded that tag loss needs to be a factor when analyzing the data obtained by this system in Atlantic Salmon, and that retention rates should be evaluated in the field through the use of other methods, such as fin clipping.
- **Acoustic Telemetry (AT)** consists of giving each fish a tag which contains a sensor, processor, battery, and modem; and it is the leading technology for tracking in some fish, providing results with high temporal and spatial resolution (Føre et al., 2018; Leander et al., 2020). This system allows for flexibility when it comes to location of

detectors/receivers (Føre et al., 2018). The signals emitted by these tags, composed of encoded data, are picked up by acoustic receivers, which can be placed strategically so the information they collect can be obtained offline or they are attached to systems which enable real time data transfer (Føre et al., 2018). Acoustic telemetry serves to monitor the behaviors of aquatic species, and the signals emitted are usually unique to each transmitter, often also indicating environmental parameters like depth and temperature. However, the detection range of the transmitter, as well as the quality and quantity of the ability to position the transmitter, is sensitive to background noise and vegetation, among other factors. Furthermore, the method in which the information is encoded, as well as power output and the technical properties of the signal transfer system, may also impact the resulting tracking data (Leander et al., 2020). Acoustic telemetry can also provide survival rates information at the population level (Chaput et al., 2018), and it has proven particularly useful for monitoring salmonids, helping scientists to observe the migration of smolts relatively regardless of turbidity and water level (Bjerck et al., 2021).

- **Camera recordings,** as video surveillance, are also used to monitor the entry and exit of migrating fish, such as salmon and trout, in order to evaluate current stock and migratory behavior, without having to rely solely on catch statistics. Survival can also be estimated using this method, and the time of migration for both adult and smolts. Cameras are placed at the bottom of the river at a cross section, mounted with underwater lights (Lamberg, 2018). The video cameras are generally installed in rivers before the migration period, from late April, and removed before freezing, mid-November at the latest (Svenning et al., 2017). The cameras are then attached to a continuous recording system, with storage that needs to be changed depending on the required storage (Lamberg, 2018). Fish that appear in the recordings are classified according to their species and type, with additional information about the date, time and direction of their journey also added (Lamberg, 2018). Fish length is usually measured to the nearest centimeter, using a reference scale in the picture (Svenning et al., 2017). Salmon are classified based on the video according to morphology, and there are certain morphological characteristics which are used for the classification (Lamberg, 2018).

The different datasets reflected on Table 2 originated from different projects and were not compiled for this thesis specifically. The data is from several years as it serves to evaluate the outmigration of salmon smolts year by year, and method by method, therefore allowing for method comparison. Although fieldwork was also planned in this project to get a practical understanding of how each method is used in the field, it was cancelled due to the SARS-CoV-2 national and local infection prevention guidelines.

Table 2. Overview of datasets available for data analyses, with method overlap in the same year in **bold.**

Location	PIT	AT	Camera
Os	**2019**, 2020	2018, **2019**, 2020	**2019**
Granvin	**2019**, 2020	2018, **2019**, 2020	2018, **2019**

The data analysis consisted in a comparison of methods in a specific river, in specific years. Conveniently, two rivers (Os and Granvin) fit the requirement for this part, which was to have all three methods collect migration data during the same year (see Appendix 1). For both rivers, that was the year 2019. By choosing to compare the results of each method in both rivers, the possibility of errors in the process of data collection is more likely to be avoided and a more accurate representation of the methods can be established. A total of 1561 and 378 salmon smolts were tagged with PIT, for Os and Granvin respectively in 2019. In the case of AT, 86 and 32 salmon smolts were tagged, for Os and Granvin respectively in 2019. For the results and discussion, we are assuming that every smolt that was tagged with PIT and AT migrated and that each group tagged by each method independently represents the entire population, so as to argue the theorethical accuracy of each method. In the case of cameras, we use the estimated annual smolt production to make our arguments.

This comparative analysis allowed for a comparison of the results that were obtained from each method and subsequently discuss the possible reasons for the significant difference, if any, in data collection. Then, it might be possible to infer, through the advantages and disadvantages of each method, which method is the most consistent and reliant. This process was meant to determine how much variation can be explained by the method of migration, and what might explain this difference.

The datasets were organized by river and by year. The values needed, such as date of migration, number of salmon smolts migrating, and the specific river were manually extracted and laid out in another .csv file for easier processing in RStudio (see Appendix 2). The datasets were originally made for each river/method/year, in order to easily plot them.

The datasets for PIT, AT, and Camera for both rivers were plotted in the beginning in order to visualize the data. Once that was done, the datasets were combined and the resulting dataset represented the method, date and outmigration captured, for each of the rivers. The combination of the methods into one dataset per river allowed for the comparative analysis which consisted of a Levene's Test to test for homogeneity of variances, and an ANOVA test to compare the mean of the independent groups, which in this case are the Camera, Acoustic Telemetry, and PIT methods. A Shapiro-Wilk test was also done to check for normal distribution of the variables, along with a test for outliers, and, finally, a simple boxplot was used to illustrate the true variance in the amount of outmigration recorded for each method in each separate river. This data analysis was done with RStudio Version 1.4.1106.

6. Results

a. Data collection methods

The resulting plots of each method showed a significant visual difference between the outmigration recorded by PIT by Camera, and Acoustic Telemetry in both Granvin and Os.

The clearest example of this difference in Os during 2019 occurred on April 24th, where PIT registered 9 salmon smolts migrating (Fig. 5), while 235 smolts were recorded by the cameras (Fig. 6), and the maximum amount of smolts migrating in a single day in the entire migration period. In the case of AT, 2 salmon smolts as recorded as migrating on April 24th (Fig. 7). Out of 1561 tagged with PIT, only 118 were recorded by PIT, and if we assume the ones tagged amount to the entire population of smolts, this represents only around 7.6% of smolts were recorded migrating. A total of 1556 smolts were recorded by cameras. Out of 86 tagged with AT, 24 salmon smolts were recorded in the outmigration at the outermost receiver, which was closest to exit of the river. This represents around 28% of the population, assuming the entire population is equal to the amount of smolts tagged by AT. The Shapiro-Wilk test result for Os was a significant p-value = 1.989e-13, meaning that the data was not normally distributed, which is why the data was later log transformed and tested again. The result was still significant in the Shapiro-Wilk test (W = 0.96791, p-value = 0.03089), meaning that the transformed data was still not normally distributed, albeit closer to a normal distribution.

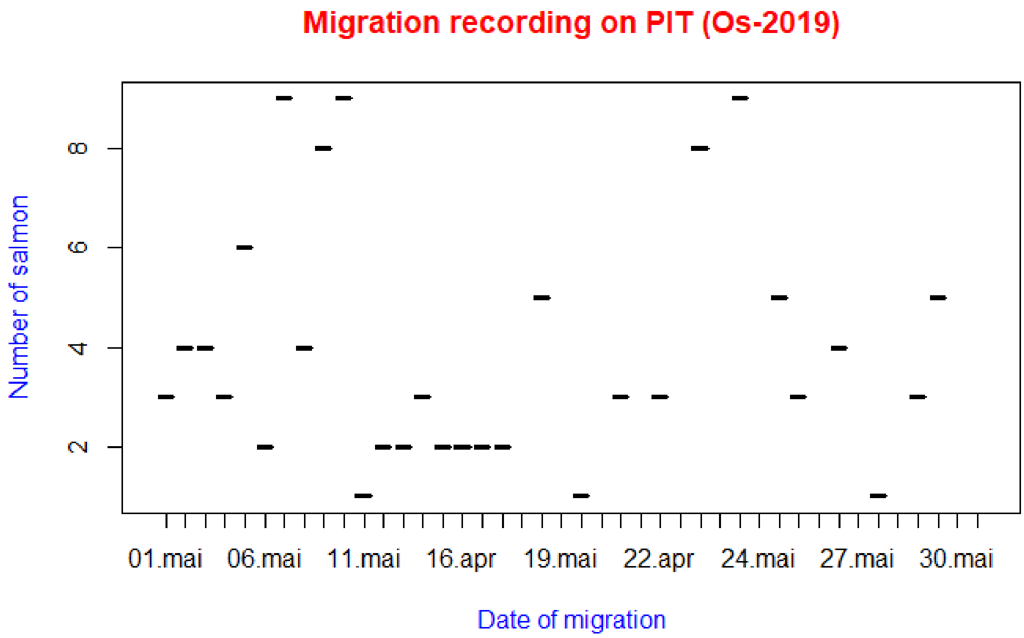

Figure 5. Migration of Salmon in the river Os recorded by PIT in 2019.

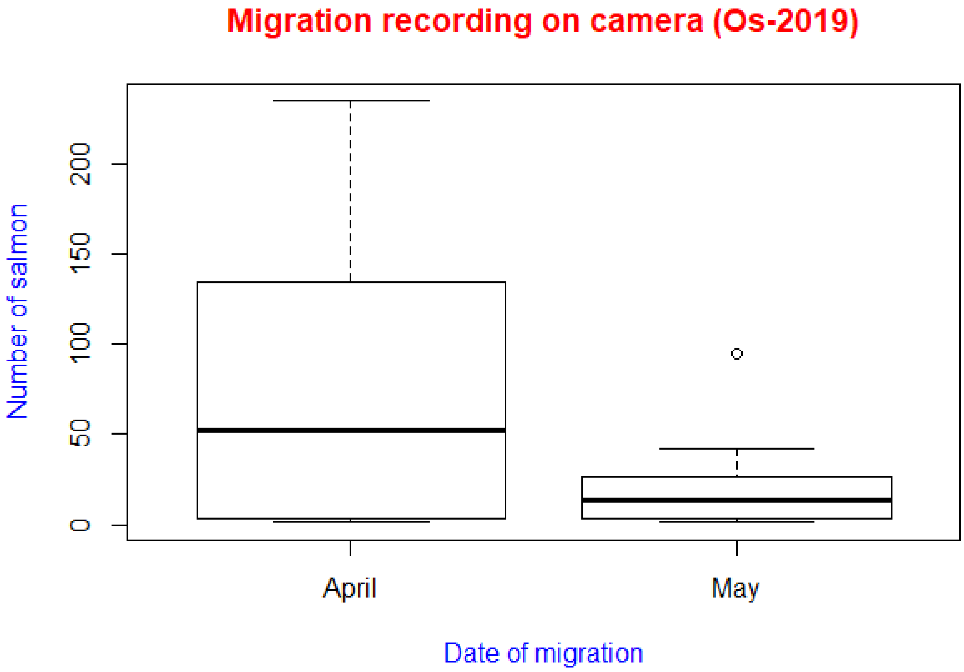

Figure 6. Migration of Salmon in the river Os recorded on cameras in 2019.

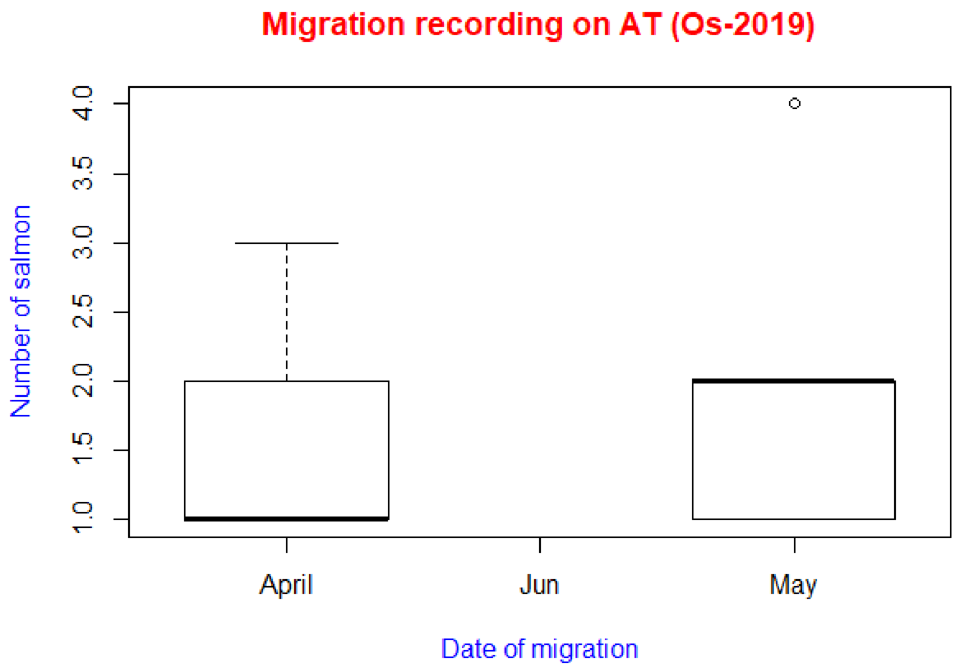

Figure 7. Migration of Salmon in the river Os recorded on AT in 2019.

The ANOVA test resulted in p-value of 1.4e-07, showing significant variance between the methods used for Os in 2019, and better illustrated in the subsequent boxplot (Fig. 8)

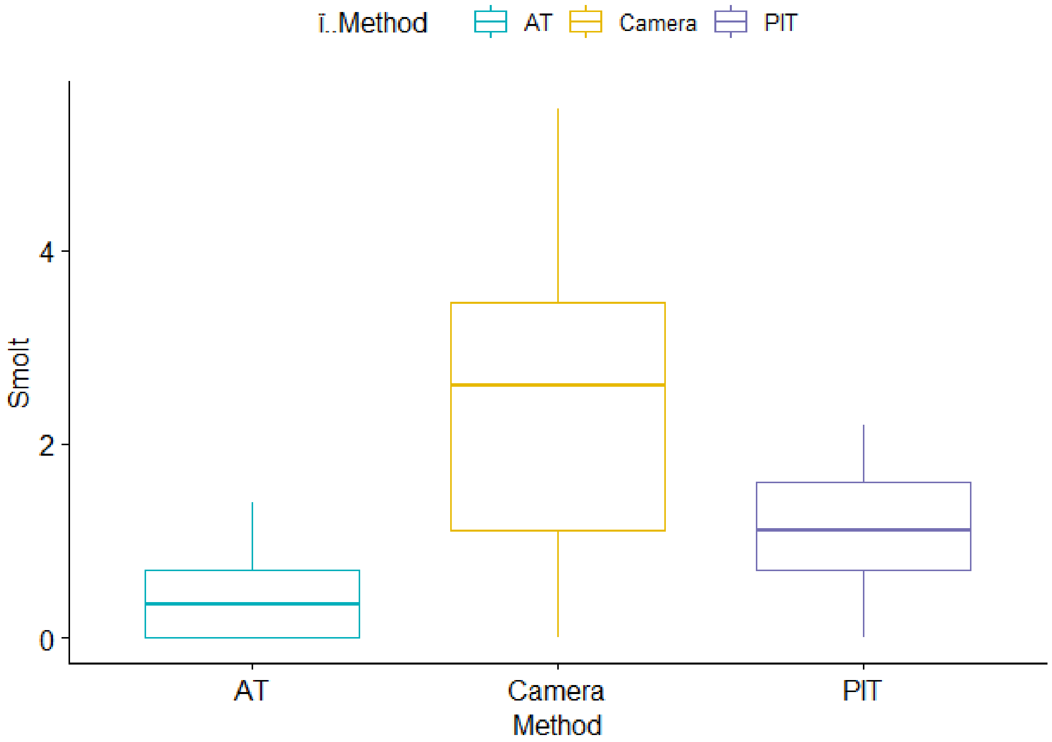

Figure 8. Boxplot illustrating the outmigration recording variance between Camera, AT, and PIT in Os, 2019.

The clearest example of this difference in Granvin during 2019 occurred on May 22nd, where PIT registered no salmon smolts migrating (Fig. 9), while 35 smolts were recorded by the cameras (Fig. 10), the maximum amount of smolts that migrated in one day of the entire migration period. In the case of AT, no salmon smolts as recorded as migrating on May 22nd (Fig. 11).

Out of 378 tagged by PIT, only 32 were recorded by PIT, and if we assume the ones tagged amount to the entire population of smolts, this represents only 8.5% of smolts were recorded migrating. A total of 150 smolts were recorded by cameras. Out of 32 tagged with AT, 11 salmon smolts were recorded in the outmigration at the outermost receiver, which was closest to exit of the river. This represents around 34% of the population, assuming the entire population is equal to the amount of smolts tagged with AT.

The Shapiro-Wilk test result for Granvin was p-value = 1.205e-10, meaning that the data was also not normally distributed, which is why the data was later log transformed and tested again.

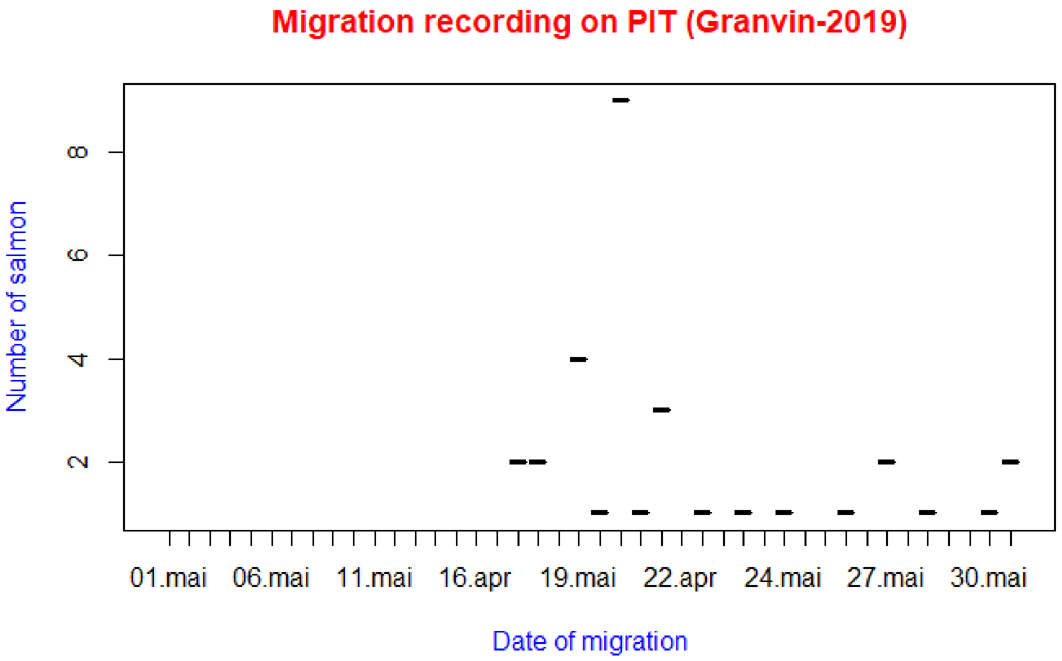

Figure 9. Migration of Salmon in the river Granvin recorded by PIT in 2019.

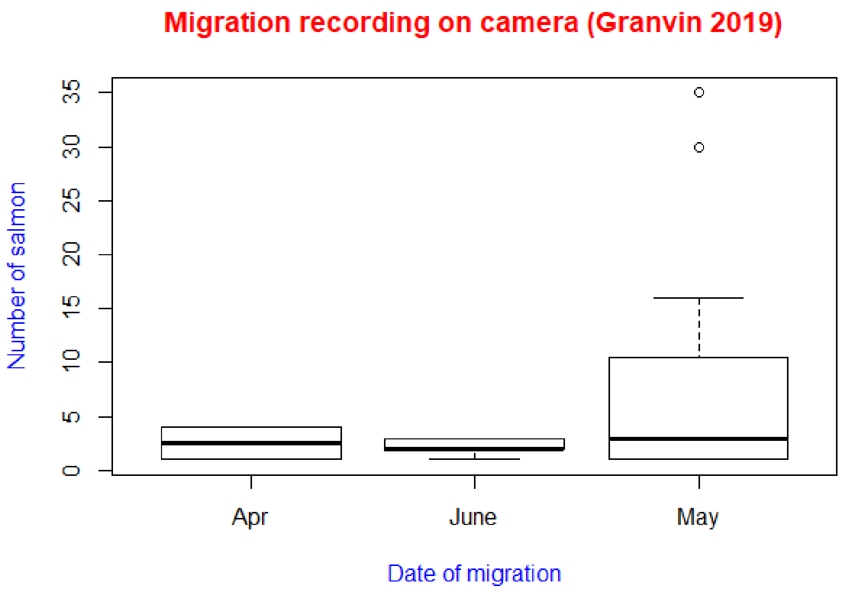

Figure 10. Migration of Salmon in the river Granvin recorded on Camera in 2019.

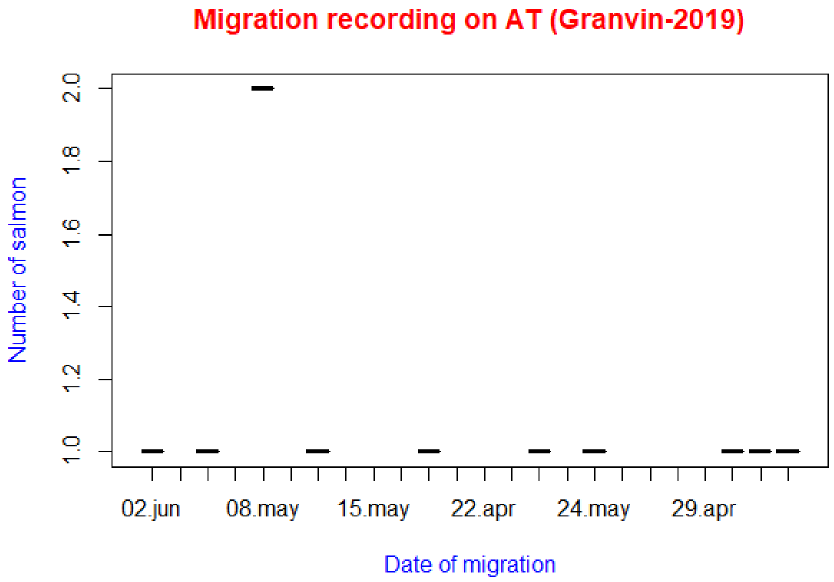

Figure 11. Migration of Salmon in the river Granvin recorded on AT in 2019.

The result was still significant in the Shapiro-Wilk test (W = 0.88874, p-value = 0.0007845), and still very far off from a normal distribution. The ANOVA test resulted in a significant p-value of 0.00582 for Granvin in 2019. The difference in outmigration recording was then illustrated with a boxplot (Fig. 12).

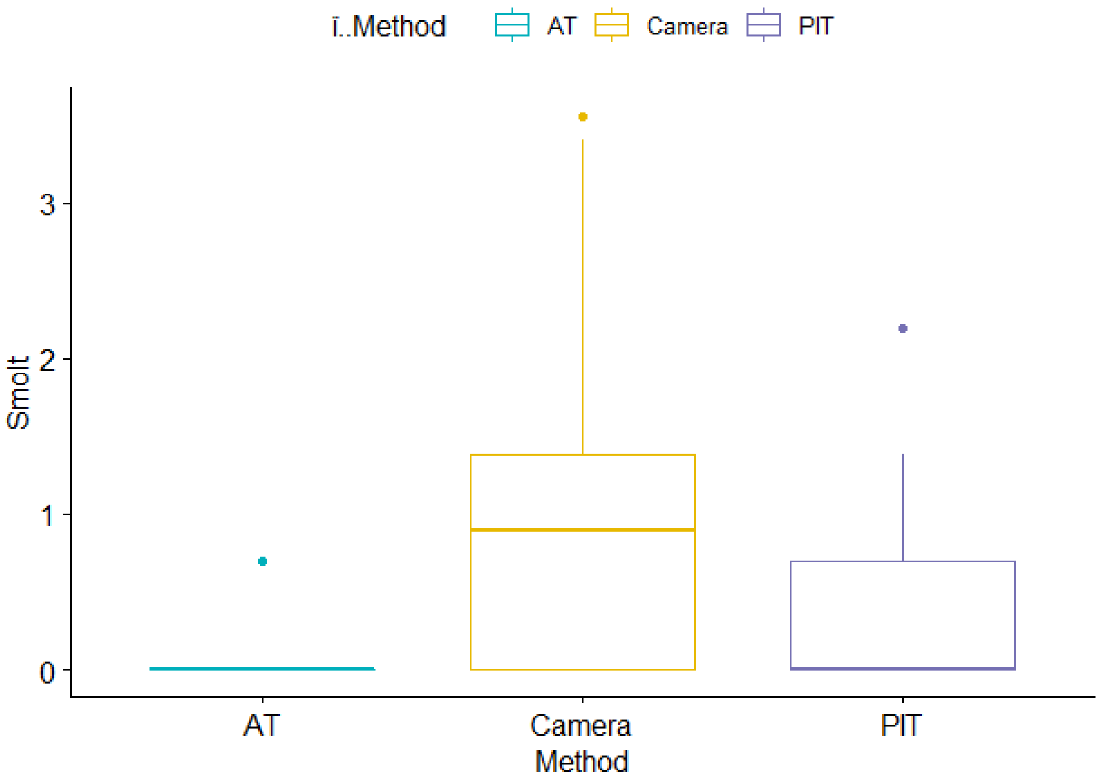

Figure 12. Boxplot illustrating the outmigration recording difference between Camera, AT and PIT in Granvin, 2019.

b. Traffic Light System

The results in this section originate from the risk assessment reports from 2018, 2019, and 2020 (Nilsen et al., 2018-2020). In 2019, the expert group stated that over such a short period of time, it was impossible to separate a real trend from a pure coincidence, making it hard to evaluate how effective, or whether effective at all, the system is at regulating the production of salmon aquaculture to a beneficial extent towards the wild salmon population it is supposed to benefit. However, through a 4-year period, we know that:

- Mortality has been stably low for PO1, PO9, PO11, PO12 and PO13
- Mortality has been at the border between low and moderate mortality for PO6, PO7, PO8, and PO10.
- There is a clear biennial salmon lice cycle for PO5, PO5, and PO8.
- Mortality increased in PO2 in recent years, when compared to 2012-2014
- Mortality decreased in recent years (2018-2020) in PO3, when compared to the period 2014-2017

7. Discussion

a. Data collection methods

An outlier test was also used for the datasets of Os and Granvin. It revealed a large number of salmon smolts registered to have migrated on April 24th in Os (235 smolts), and May 21st in Granvin (30 smolts). Both outliers were registered by cameras. They were however not removed as the number of salmons registered were also not likely impossible values, as it is likely that the migration of these smolts did occur in the numbers that were registered. However, it must be kept in mind that monitoring migration through cameras also involves human error and confusing salmon smolts with trout smolts.

Each data collection method evaluated in this project has its advantages and its limitations (Table 3) when it comes to measuring salmon smolt migration.

Table 3. Data collection methods comparison with advantages and limitations, focusing on the problem of measuring migration timing in salmon smolts.

Method	Advantages	Limitations
Acoustic Telemetry	• High detection probability (80-100%) • Flexibility in the placement of detection arrays • Larger detection ranges than PIT	• Transmitter detection range is subject to background noise • Noise and temperature may affect the derived position of the transmitter • Larger volume tag than PIT
PIT	• Internal, permanent • Works in any weather • Does not affect growth, mating, predatorial susceptibility or swimming speed • High reliability and reading accuracy (as long as it is in range) • Can be re-used	• PIT tags and readers must operate at the same frequency, meaning not every PIT tag can be read by the same reader • Tag can move within the body or be recognized as a foreign object and rejected • Small size of animals may affect tagging

	• Does not need a battery	• Tag expulsion can occur through egg-laying, intestines or through the incision • Low detection range (0.4 meters)
Camera	• Allows checking for lice attached to the fish and damage left behind from lice • Possible to evaluate differences in lice infestation over several years, size of fish, and watercourses • Samples an entire population and not just a subset, provided that there are suitable conditions	• Visibility in the water can be reduced to the point of missing fish • Artificial lighting may affect behavior patterns and cause fish to be repulsed by the water passage

(Lamberg, 2018; Føre et al., 2018; Leander et al., 2020; Foldvik & Kvingedal, 2018; Gibbons & Andrews, 2004)

Less than 10% respectively of the fish that were PIT-tagged both in Os and Granvin were recorded to have migrated when picturing the tagged fish as the entire population. By contrast, cameras in Os recorded almost the same number of fish as were tagged, and in Granvin, the migration caught on camera was closer to 40% of all fish that were PIT-tagged. However, when comparing the number of fish that were recorded in Granvin by the cameras to the estimated annual smolt production (Nilsen et al., 2018), the percentage of smolts that were caught on camera was only about 2.5%. The same seems to occur in Os, albeit to a lesser extent, where at first glance, the cameras seem to have registered a very large percentage of the population in comparison, when only 5.6% of the estimated annual smolt production was recorded, which is still lower than those recorded by the PIT method.

In the case of AT, if we picture the tagged fish as the entire population of smolts migrating, as it is supposed to be representative, then the recorded numbers and thus the accuracy is arguably better. For Os, AT recorded around 34% of the population, and 28% for Granvin.

According to the Shapiro-Wilk test for Os and Granvin, both datasets were not normally distributed and so the data was log-transformed. One of the reasons the data was kept log/transformed, despite it still not being normally distributed, was that, to some degree, more for the data from Os than from Granvin, the log-transformation improved the distribution of the data to a closer-to-normal degree. Other data transformation methods were attempted, but the closest to normality was log-transformed. This was especially obvious in the non-log-transformed boxplots, where the variance was very difficult to visualize and it resulted in a cluttered graphic, which was the second reason why the log-transformation was kept. Salmon migration is inherently multimodal (Bjerck et al. 2021), which is where the non-normality of the data is likely to have originated, not skewness itself. Ultimately, the log-transformation was kept to make the visualization of the variance between methods easier.

The difference in the data collection methods might be explained by several factors. After the fish are PIT-tagged and the sensors are set up, human error is taken out of the equation. Camera data is entered manually, and people review hours of footage in order to identify the fish passing through it. This may lead to fish being counted as salmon smolt when they belong to another species, evidenced by the fact that some registered data identifies the fish as simply being a “smolt” but without distinguishing between Salmon and Trout. Lighting from cameras may also cause the fish to be repulsed by the water passage where they are set up, and so they are not registered, though the lighting is necessary for visibility. High-water discharge may also affect camera visibility. PIT sensors, on the other hand, work in any weather, though their detection range is low. However, there are legal limitations to how many fish can be tagged, and so PIT only allows for a sample size, instead of sampling the entire population as cameras do. Cameras also allow for some evaluation of lice infestation, as one can sometimes check for lice attached to the fish or damage left behind from the lice, depending on visibility. There are also legal limitations to how many fish can be tagged with AT. Like PIT, it is also placed in the body, however the AT tag is bigger. It does have a larger range of detection than PIT, thus giving a detection probability of 80-100%, which may explain why the theorethical accuracy of this method is the highest of the three.

b. Traffic Light System

The short period of ecological time during which the TLS has been implemented makes it difficult to measure how effective it is at regulating production to an extent that is beneficial to wild salmon populations that are affected increasing salmon lice infestations.

A particular drawback of the TLS is that migration timing cannot be controlled, and this is a very sensitive parameter. While there are methods to fight the lice, these are limited and may even be polluting. However, there's potential in spatial separation of farms to limit the effects of lice (Bøhn et al., 2020; Myksvoll et al., 2020; Anon., 2019).

It is important when seeking to improve on the TLS that a comparison is drawn between the timing of lice blooms and the timing of salmon smolt migration, in order to provide a better assessment. (Bøhn et al., 2020). With new policies being introduced, it is expected that there will be errors, but learning from these errors will lead to a better system over time (Cappelen & Mjøset, 2009). Another element that must be taken into account is the timing of oceanographic events, which also has a role in lice concentrations and dispersal (Myksvoll et al., 2020).

What the TLS does well is to provide indirect financial and reputational incentives to those companies who manage to keep sea lice infestations to a minimum in their production areas and do not go over the parameters that have been set. It provides financial incentives by continuing to allow production at the same level (yellow) or allowing to raise production (green), instead of losing money because of a reduction in production (red). The reputational incentive is mainly how the industry is perceived by the public, and whether it is environmentally friendly, which in turn may lead to more financial gains or losses. The financial and reputational risks to not obtain a green light in the production area that the companies operate has been reflected in the recent lawsuit.

8. **Conclusion**

When comparing PIT, Camera, and AT collection methods, based on the advantages and limitations of these methods, and keeping in mind the results of the data analysis in Os and Granvin, Acoustic Telemetry appears to result in a more accurate data collection method between the three. This is of course based on the idea that the population tagged is representative of the entire population, which is an important element to keep in mind. When it comes to the Traffic Light System, by picking sea lice as an indicator, the TLS was made a predictable system, and while it is impossible to see a trend yet as not enough time has passed, it financially and reputationally encourages companies to increasingly become sustainable, which is the ultimate goal for a vital Norwegian industry that wishes to continue to grow their production levels.

Future research should be focused on continuing to improve migration timing estimates through the different data collection methods and on evaluating the trend of the Traffic Light System as a regulatory system that positively impacts wild salmon populations.

9. References

- Anon. (2015). Norwegian salmon farming: Predictable and environmentally sustainable growth. Retrieved from https://www.regjeringen.no/en/dokumenter/norwegian-salmon-farming/id2461650/
- Anon. (2019). Notat om inkludering av nye data fra produksjonsområde PO3 og PO4. Retrieved from https://www.regjeringen.no/contentassets/68986c2c2d6d4443b5a057718317a210ekspertgruppens-vurdering-av-nye-data-po3-og-po4-notat.pdf
- Bailey, J. L., & Eggereide, S. S.. (2020). Indicating sustainable salmon farming: The case of the new Norwegian aquaculture management scheme. Marine Policy, 117, 103925. https://doi.org/10.1016/j.marpol.2020.103925
- Biomark. (2019). Biomark - RFID and PIT technology. Retrieved December 10, 2019, from https://www.biomark.com/faqs
- Bjerck, H. B., Urke, H. A., Haugen, T. O., Alfredsen, J. A., Ulvund, J. B., & Kristensen, T.. (2021). Synchrony and multimodality in the timing of Atlantic salmon smolt migration in two Norwegian fjords. Scientific Reports, 11(1). https://doi.org/10.1038/s41598-021-85941-9
- Bjørn, P. A., Finstad, B., & Kristoffersen, R.. (2001). Salmon lice infection of wild sea trout and Arctic char in marine and freshwaters: the effects of salmon farms. Aquaculture Research, 32(12), 947–962. https://doi.org/10.1046/j.1365-2109.2001.00627.x
- Bjørnar Michaelsen-Svendsen (2019). Implementation of the traffic light system in norwegian salmon aquaculture - success or failure for whom? Master’s thesis, Tromsø.
- Bøhn, T., Gjelland, K. Ø., Serra‐Llinares, R. M., Finstad, B., Primicerio, R., Nilsen, R., Karlsen, Ø., Sandvik, A. D., Skilbrei, O. T., Elvik, K. M. S., Skaala, Ø., & Bjørn, P. A.. (2020). Timing is everything: Survival of Atlantic salmon Salmo salar postsmolts during events of high salmon lice densities. Journal of Applied Ecology, 57(6), 1149–1160. https://doi.org/10.1111/1365-2664.13612
- Bowen, G. A. (2009). Document Analysis as a Qualitative Research Method. Qualitative Research Journal, Vol 9(2), pp. 27-40. doi:10.3316/QRJ0902027

- Brakstad, O. M., Hagspiel, V., Lavrutich, M. N., & Matanovic, D.. (2019). Optimal investment decisions in lice-fighting technologies: A case study in Norway. Aquaculture, 504, 300–313. https://doi.org/10.1016/j.aquaculture.2019.01.040
- Bron, J.E., Sommerville, C., Jones, M.W., & Rae, G.H. (1991). The settlement and attachment of early stages of the salmon louse, Lepeophtheirus salmonis (Copepoda: Caligidae) on the salmon host, Salmo salar. Journal of Zoology, 224, 201-212.
- Butler JR (2002). Wild salmonids and sea louse infestations on the west coast of Scotland: sources of infection and implications for the management of marine salmon farms. Pest Manag Sci 58: 595−608
- Cappelen, Å., & Mjøset, L.. (2012). Can Norway be a Role Model for Natural Resource Abundant Countries? (pp. 44–72). https://doi.org/10.1093/acprof:oso/9780199660704.003.0003
- Carlsen, K. T., Berg, O. K., Finstad, B. & Heggberget, T. G. (2004). Diel periodicity and environmental influence on the smolt migration of Arctic charr, Salvelinus alpinus, Atlantic salmon, Salmo salar, and brown trout, Salmo trutta, in northern Norway. Environmental Biology of Fishes 70, 403–413.
- Chaput, G., Carr, J., Daniels, J., Tinker, S., Jonsen, I., & Whoriskey, F. (2019). Atlantic salmon (Salmo salar) smolt and early post-smolt migration and survival inferred from multi-year and multi-stock acoustic telemetry studies in the Gulf of St. Lawrence, northwest Atlantic. ICES Journal of Marine Science, 76(4), 1107–1121. https://doi.org/10.1093/icesjms/fsy156
- Davidsen, J. G., Svenning, M. A., Orell, P., Yoccoz, N., Dempson, J. B., Niemel¨a, E., Klemetsen, A., Lamberg, A. & Erkinaro, J. (2005). Spatial and temporal migration of wild Atlantic salmon smolts determined from a video camera array in the sub-Arctic River Tana. Fisheries Research 74, 210–222.
- Thorstad, E. B., Whoriskey, F., Uglem, I., Moore, A., Rikardsen, A. H., & Finstad, B. (2012). A critical life stage of the Atlantic salmon Salmo salar: behaviour and survival during the smolt and initial post-smolt migration. Journal of fish biology, 81(2), 500–542. https://doi.org/10.1111/j.1095-8649.2012.03370.x
- Finstad, B. & Jonsson, N. (2001). Factors influencing the yield of smolt releases in Norway. Nordic Journal of Freshwater Research 75, 37–55.

- Foldvik, A., & Kvingedal, E.. (2018). Long-term PIT tag retention rates in Atlantic salmon (Salmo salar). Animal Biotelemetry, 6(1). https://doi.org/10.1186/s40317-018-0147-1
- Føre, M., Svendsen, E., Alfredsen, J. A., Uglem, I., Bloecher, N., Sveier, H., Sunde, L. M., & Frank, K.. (2018). Using acoustic telemetry to monitor the effects of crowding and delousing procedures on farmed Atlantic salmon (Salmo salar). Aquaculture, 495, 757–765. https://doi.org/10.1016/j.aquaculture.2018.06.060
- Forseth, T., Barlaup, B. T., Finstad, B., Fiske, P., Gjøsæter, H., Falkegård, M., Hindar, A., Mo, T. A., Rikardsen, A. H., Thorstad, E. B., Vøllestad, L. A., & Wennevik, V.. (2017). The major threats to Atlantic salmon in Norway. ICES Journal of Marine Science, 74(6), 1496–1513. https://doi.org/10.1093/icesjms/fsx020
- Samsing, F., Oppedal, F., Dalvin, S., Johnsen, I., Vågseth, T., & Dempster, T.. (2016). Salmon lice (Lepeophtheirus salmonis) development times, body size, and reproductive outputs follow universal models of temperature dependence. Canadian Journal of Fisheries and Aquatic Sciences, 73(12), 1841–1851. https://doi.org/10.1139/cjfas-2016-0050
- Froese, R., and Pauly, D. 2009. FishBase [online]. Available from http://www.fishbase.org [accessed 12 December 2020].
- Gibbons, W. J., & Andrews, K. M. (2004). PIT Tagging: Simple Technology at Its Best. BioScience, 54(5), 447-454. doi:10.1641/0006-3568(2004)054[0447:Ptstai]2.0.Co;2
- Gillibrand, P., Hay, D., Penston, M., & Murray, A. G. (2005). Sea lice and sea trout: are salmon farms causing increased parasitism on wild salmonids in Scotland? Ocean Challenge, 14(2), 14-21.
- Gross, M. R., Coleman, R. M., & McDowall, R. M. (1988). Aquatic productivity and the evolution of diadromous fish migration. Science (New York, N.Y.), 239(4845), 1291–1293. https://doi.org/10.1126/science.239.4845.1291
- Gullestad, P., Bjørgo, S., Eithun, I., Ervik, A., Gudding, R., Hansen, H., . . . Skarra, H. (2011). Effektiv og bærekraftig arealbruk i havbruksnæringen - areal til begjær. Oslo: The Norwegian The Ministry of Fisheries and Coastal Affairs. doi:ISBN: 978-82-92075-05-0

- Hamre, L. A., Eichner, C., Caipang, C. M. A., Dalvin, S. T., Bron, J. E., Nilsen, F., Boxshall, G., & Skern-Mauritzen, R. (2013). The Salmon Louse Lepeophtheirus salmonis (Copepoda: Caligidae) Life Cycle Has Only Two Chalimus Stages. PLOS ONE, 8(9), e73539. https://doi.org/10.1371/journal.pone.0073539
- Hansen, L. P. & Jonsson, B. (1985). Downstream migration of hatchery-reared smolt of Atlantic salmon (Salmo salar L.) in the River Imsa. Aquaculture 45, 237–248.
- Haraldstad, T., Kroglund, F., Kristensen, T., Jonsson, B., & Haugen, T. O. (2017). Diel migration pattern of Atlantic salmon (Salmo salar) and sea trout (Salmo trutta) smolts: an assessment of environmental cues. Ecology of Freshwater Fish, 26(4), 541-551. doi:https://doi.org/10.1111/eff.12298
- Arnold, G.. (2011). F R Harden Jones. ICES Journal of Marine Science, 68(10), 2005–2006. https://doi.org/10.1093/icesjms/fsr158
- Harte, A. J., Bowman, A. S., Salama, N. K., & Pert, C. C. (2017). Factors influencing the long-term dynamics of larval sea lice density at east and west coast locations in Scotland. Diseases of aquatic organisms, 123(3), 181–192. https://doi.org/10.3354/dao03095
- Head, B. W. (2008). Wicked Problems in Public Policy. Public Policy. Curtin University of Technology. https://search.informit.org/doi/10.3316/informit.662880306504754
- Hoar, W. S. (1988). The physiology of smolting salmonids. In Fish Physiology, Vol. XIB (Hoar, W. S. & Randall, D. J., eds), pp. 275–343. New York, NY: Academic Press.
- Howlett, M. (2014). Policy Design: What, Who, How and Why? I C. Halpern, P. Lascoumes, & P. Galès, L'instrumentation et ses effets. : Débats et mises en perspective théoriques [Instrumentation and its effects. : Debates and theoretical perspectives] (ss. 281-315). Paris: Presses de Sciences Po. doi:ISBN : 978-2-7246-1456-5
- Hulbak, M. A. 2020. Are migration timing estimates based on tagged Atlantic salmon smolts (Salmo salar) biased? The University of Bergen.
- Hvidsten, N. A., Heggberget, T. G. & Jensen, A. J. (1998). Sea water temperature at Atlantic salmon smolt enterance. Nordic Journal of Freshwater Research 74, 79–86.

- Hvidsten, N. A., Jensen, A. J., Rikardsen, A. H., Finstad, B., Aure, J., Stefansson, S., Fiske, P. & Johnsen, B. O. (2009). Influence of sea temperature and initial marine feeding on survival of Atlantic salmon Salmo salar post-smolts from the Rivers Orkla and Hals, Norway. Journal of Fish Biology 74, 1532–1548.
- Hvidsten, N. A., Jensen, A. J., Vivas, H., Bakke, Ø. & Heggberget, T. G. (1995). Downstream migration of Atlantic salmon smolts in relation to water flow, water temperature, moon phase and social interaction. Nordic Journal of Freshwater Research 70, 38–48.
- Iversen, A., Andreassen, O., Hermansen, Ø., Larsen, T.A., Terjesen, B.F., (2013). Oppdrettsteknologi og konkurranseposisjon. Nofima report 32/2013.
- Johnson, S.C., and Albright, L.J. 1991. The developmental stages of Lepeophtheirus salmonis (Krøyer, 1837) (Copepoda: Caligidae). Can. J. Zool. 69(4): 929–950. doi:10.1139/z91-138.
- Jonsson, B. & Ruud-Hansen, J. (1985). Water temperature as the primary influence on timing of seaward migrations of Atlantic salmon (Salmo salar) smolts. Canadian Journal of Fisheries and Aquatic Sciences 42, 593–595.
- Klemetsen, A., Amundsen, P.-A., Dempson, J. B., Jonsson, B., Jonsson, N., O’Connell, M. F. & Mortensen, E. (2003). Atlantic salmon Salmo salar L., brown trout Salmo trutta L. and Arctic charr Salvelinus alpinus (L.): a review of aspects of their life histories. Ecology of Freshwater Fish 12, 1–59.
- Klemetsen, A., Amundsen, P.-A., Dempson, J. B., Jonsson, B., Jonsson, N., O'Connell, M. F., & Mortensen, E.. (2003). Atlantic salmon Salmo salar L., brown trout Salmo trutta L. and Arctic charr Salvelinus alpinus (L.): a review of aspects of their life histories. Ecology of Freshwater Fish, 12(1), 1–59. https://doi.org/10.1034/j.1600-0633.2003.00010.x
- Kristoffersen, A. B., Qviller, L., Helgesen, K. O., Vollset, K. W., Viljugrein, H., & Jansen, P. A. (2018). Quantitative risk assessment of salmon louse-induced mortality of seaward-migrating post-smolt Atlantic salmon. Epidemics, 23, 19–33. https://doi.org/10.1016/j.epidem.2017.11.001
- Lamberg, A. (2018). Bestandsovervåking av laks og sjøørret i Granvinsvassdraget 2018, SNArapport 14/2019. 61 s.
- Leander, J., Klaminder, J., Jonsson, M., Brodin, T., Leonardsson, K., & Hellström, G. (2020). The old and the new: evaluating performance of acoustic telemetry

systems in tracking migrating Atlantic salmon (Salmo salar) smolt and European eel (Anguilla anguilla) around hydropower facilities. Canadian Journal of Fisheries and Aquatic Sciences, 77(1), 177-187. doi:10.1139/cjfas-2019-0058

- Lockie, S. (2015). What is environmental sociology? Environmental Sociology, 1(3), 139–142. https://doi.org/10.1080/23251042.2015.1066084
- Lövbrand E. (2014) Knowledge and the Environment. In: Betsill M.M., Hochstetler K., Stevis D. (eds) Advances in International Environmental Politics. Palgrave Macmillan, London. https://doi.org/10.1057/9781137338976_7
- McCormick, S.D. (2013). Smolt physiology and endocrinology. In Fish physiology: euryhaline fishes. Vol. 32. Edited by S.D. McCormick, A.P. Farrell, and C.J. Brauner. Academic Press, San Diego, Calif. pp. 199–251.
- McCormick, S.D., Hansen, L.P., Quinn, T.P., and Saunders, R.L. (1998). Movement, migration, and smolting of Atlantic salmon (Salmo salar). Can. J. Fish. Aquat. Sci. 55(S1): 77–92. doi:10.1139/d98-011.
- McCormick, S.D., Saunders, R.L., Henderson, E.B., and Harmon, P.R. (1987). Photoperiod control of parr–smolt transformation in Atlantic salmon (Salmo salar): changes in salinity tolerance, gill Na+, K+-ATPase activity and thyroid hormones. Can. J. Fish. Aquat. Sci. 44(8): 1462–1468. doi:10.1139/f87-175.
- Mohn, A., Vollset, K., & Karlsbakk, E.. (2020). Making the best of lousy circumstances: the impact of salmon louse Lepeophtheirus salmonis on depth preference of sea trout Salmo trutta. Aquaculture Environment Interactions, 12, 215–229. https://doi.org/10.3354/aei00360
- MTIF. (2015). Forutsigbar og miljømessig bærekraftig vekst i norsk lakse- og ørretoppdrett. Oslo: The Norwegian Ministry of Trade, Industry and Fishery.
- Myksvoll, M., Sandvik, A., Johnsen, I., Skarðhamar, J., & Albretsen, J. (2020). Impact of variable physical conditions and future increased aquaculture production on lice infestation pressure and its sustainability in Norway. Aquaculture Environment Interactions, 12, 193–204. https://doi.org/10.3354/aei00359
- Nilsen, F., Ellingsen, I., Finstad, B., Helgesen, K. O., Karlsen, Ø., Sandvik, A. D., ... & Myksvoll, M. S. (2018). Vurdering av lakselusindusert villfiskdødelighet per produksjonsområde i 2018. Rapport fra ekspertgruppe for vurdering av lusepåvirkning Appendix, 2, 62.

- Nilsen, F., Ellingsen, I., Finstad, B., Helgesen, K. O., Karlsen, Ø., Sandvik, A. D., ... & Myksvoll, M. S. (2019). Vurdering av lakselusindusert villfiskdødelighet per produksjonsområde i 2019. Rapport fra ekspertgruppe for vurdering av lusepåvirkning.
- Nilsen, F., Ellingsen, I., Finstad, B., Helgesen, K. O., Karlsen, Ø., Sandvik, A. D., ... & Myksvoll, M. S. (2020). Vurdering av lakselusindusert villfiskdødelighet per produksjonsområde i 2020. Rapport fra ekspertgruppe for vurdering av lusepåvirkning.
- Otero, J., L'Abée-Lund, J. H., Castro-Santos, T., Leonardsson, K., Storvik, G. O., Jonsson, B., Dempson, B., Russell, I. C., Jensen, A. J., Baglinière, J.-L., Dionne, M., Armstrong, J. D., Romakkaniemi, A., Letcher, B. H., Kocik, J. F., Erkinaro, J., Poole, R., Rogan, G., Lundqvist, H., … Vøllestad, L. A.. (2014). Basin-scale phenology and effects of climate variability on global timing of initial seaward migration of Atlantic salmon (Salmo salar). Global Change Biology, 20(1), 61–75. https://doi.org/10.1111/gcb.12363
- Pike, A. W., & Wadsworth, S. L. (1999). Sealice on salmonids: their biology and control. Advances in parasitology, 44, 233–337. https://doi.org/10.1016/s0065-308x(08)60233-x
- Pike, A., Mackenzie, K., and Rowand, A. (1993). Ultrastructure of the frontal filament in chalimus larvae of Caligus elongatus and Lepeophtheirus salmonis from Atlantic salmon, Salmo salar. In Pathogens of wild and farmed fish: sea lice. Edited by G.A. Boxshall and D. Defaye. Ellis Horwood Ltd., West Sussex. pp. 99–113.
- Revie, C. W., Gettinby, G., Treasurer, J. W., Rae, G. H., & Clark, N. (2002). Temporal, environmental and management factors influencing the epidemiological patterns of sea lice (Lepeophtheirus salmonis) infestations on farmed Atlantic salmon (Salmo salar) in Scotland. Pest management science, 58(6), 576–584. https://doi.org/10.1002/ps.476
- Riley, W. D., Eagle, M. O. & Ives, S. J. (2002). The onset of downstream movement of juvenile Atlantic salmon, Salmo salar L., in a chalk stream. Fisheries Management and Ecology 9, 87–94.
- Sigholt, T. & Finstad, B. (1990). Effect of low temperature on seawater tolerance in Atlantic salmon (Salmo salar) smolts. Aquaculture 84, 167–172.

- Snyder, H.. (2019). Literature review as a research methodology: An overview and guidelines. Journal of Business Research, 104, 333–339. https://doi.org/10.1016/j.jbusres.2019.07.039
- Sogn og Fjordane Tingrett. (2021). Gyldigheita av kapasitetsjusteringsforskrifta. Retrieved from https://www.jus.uio.no/nifs/forskning/arrangementer/gjesteforelesninger-seminarer/havbruksrett/2021/tingrettens-dom.pdf
- SSB. (2018). *Akvakultur*.
- SSB. (2019). 07326: Akvakultur. Salg av slaktet matfisk, etter fiskeslag (F) 1976 - 2017.
- William Stoichevski. Norway's traffic light aquaculture zones. 2018. Salmon Business. Accessed 5th of November 2021 <https://salmonbusiness.com/norways-growth-allowance-auctions-would-punish-the-green-seafood-group-says/>
- Svenning, M., Lamberg, A., Dempson, B., Strand, R., Hanssen, Øyvind K., & Fauchald, P. (2017). Incidence and timing of wild and escaped farmed Atlantic salmon (Salmo salar) in Norwegian rivers inferred from video surveillance monitoring. Ecology of Freshwater Fish, 26(3), 360–370. https://doi.org/10.1111/eff.12280
- Taranger G. L., Svart., Kvamme B. O., Kristiansen T. S., and Boxaspen K. (Eds) 2014. Risk assessment of Norwegian aquaculture 2013 (in Norwegian). Fisken og Havet, Særnummer 2-2014.
- Taranger, G. L., Karlsen, Ø., Bannister, R. J., Glover, K. A., Husa, V., Karlsbakk, E., Kvamme, B. O., Boxaspen, K. K., Bjørn, P. A., Finstad, B., Madhun, A. S., Morton, H. C., & Svåsand, T.. (2015). Risk assessment of the environmental impact of Norwegian Atlantic salmon farming. ICES Journal of Marine Science, 72(3), 997–1021. https://doi.org/10.1093/icesjms/fsu132
- Tétard, S., Maire, A., Lemaire, M., De Oliveira, E., Martin, P., & Courret, D.. (2019). Behaviour of Atlantic salmon smolts approaching a bypass under light and dark conditions: Importance of fish development. Ecological Engineering, 131, 39–52. https://doi.org/10.1016/j.ecoleng.2019.02.021
- The Norwegian Government. (2011, August). Høring – Rapport fra et ekspertutvalg om effektiv og bærekraftig arealbruk i havbruksnæringen. Retrieved May 2, 2019, from regjeringen.no: https://www.regjeringen.no/no/dokumenter/horing--rapport-

fra-et-ekspertutvalg-om-/id633402/?expand=horingssvar&lastvisited=Fornyings,-_administrasjons-_og_kirkedepartementet

- The Norwegian Government. (2018a, September 20). Høring – melding til Stortinget om vekst i norsk lakse- og ørretoppdrett. Retrieved May 5, 2019, from regjeringen.no: https://www.regjeringen.no/no/dokumenter/horing--melding-til-stortinget-om-vekst-i-norsk-lakse--og-orretoppdrett/id2076332/?expand=horingssvar&lastvisited=Troms_fylkeskommune
- The Norwegian Government. (2018b, September 20). Forslag til regelverk for å implementere nytt system for kapasitetsjusteringer i lakse- og ørretoppdrettystem for kapasitetsjusteringer i lakse- og ørretoppdrett. Retrieved May 5, 2019, from regjeringen.no: https://www.regjeringen.no/no/dokumenter/forslag-til-regelverk-for-a-implementere-nytt-system-for-kapasitetsjusteringer-i-lakse--og-orretoppdrett/id2505908/
- Thorpe, J. E., Mangel, M., Metcalfe, N. B. & Huntingford, F. A. (1998). Modelling the proximate basis of salmonid life-history variation, with application to Atlantic salmon, Salmo salar L. Evolutionary Ecology 12, 581–599.
- Thorstad, E. B., Whoriskey, F., Rikardsen, A. H. & Aarestrup, K. Aquatic nomads: The life and migrations of the Atlantic salmon. In Atlantic Salmon Ecology (eds Aas, Ø. et al.) 1–32 (Wiley-Blackwell, 2010) https:// doi. org/ 10. 1002/ 97814 44327 755. ch1.
- Thorstad, E., Todd, C., Uglem, I., Bjørn, P., Gargan, P., Vollset, K., Halttunen, E., Kålås, S., Berg, M., & Finstad, B.. (2015). Effects of salmon lice Lepeophtheirus salmonis on wild sea trout Salmo trutta—a literature review. Aquaculture Environment Interactions, 7(2), 91–113. https://doi.org/10.3354/aei00142
- Thorstad, E.B. & Finstad, B. (2018). Impacts of salmon lice emanating from salmon farms on wild Atlantic salmon and sea trout. NINA Report 1449: 1-22.
- Tiller, R. G., De Kok, J.-L., Vermeiren, K., & Thorvaldsen, T.. (2017). Accountability as a Governance Paradox in the Norwegian Salmon Aquaculture Industry. Frontiers in Marine Science, 4. https://doi.org/10.3389/fmars.2017.00071
- Torrissen, O., Jones, S., Asche, F., Guttormsen, A., Skilbrei, O. T., Nilsen, F., Horsberg, T. E., & Jackson, D. (2013). Salmon lice--impact on wild salmonids and

salmon aquaculture. Journal of fish diseases, 36(3), 171–194. https://doi.org/10.1111/jfd.12061

- Tucker, C. S., Sommerville, C., & Wootten, R.. (2000). An Investigation into the Larval Energetics and Settlement of the Sea Louse, Lepeophtheirus salmonis, an Ectoparasitic Copepod of Atlantic salmon, Salmo salar.. Fish Pathology, 35(3), 137–143. https://doi.org/10.3147/jsfp.35.137
- Urke, H.A., Haugen, T.O., Kjærstad, G., Alfredsen, J.A. & Kristensen, T. (2018). Laks- og aurebestanden i Strynevassdraget; vandringsmønsteret hjå laksesmolt og aure, ungfiskproduksjon og botndyr. - MINA fagrapport 48. 56 s.
- Vitenskapelig råd for lakseforvaltning. 2019. Wild Atlantic Salmon. Accessed 5th of November 2021, < https://www.vitenskapsradet.no/Nyheter/Nyhetsartikkel/ArticleId/4854/Status-of-wild-Atlantic-salmon-in-Norway-2019>
- Vollset, K. W., Barlaup, B. T., Skoglund, H., Normann, E. S., & Skilbrei, O. T. (2014). Salmon lice increase the age of returning Atlantic salmon. Biology Letters, 10, 20130896. https://doi.org/10.1098/rsbl.2013.0896
- Vollset, K. W., Dohoo, I., Karlsen, Ø., Halttunen, E., Kvamme, B. O., Finstad, B., Wennevik, V., Diserud, O. H., Bateman, A., Friedland, K. D., Mahlum, S., Jørgensen, C., Qviller, L., Krkošek, M., Åtland, Å., & Barlaup, B. T.. (2018). Disentangling the role of sea lice on the marine survival of Atlantic salmon. ICES Journal of Marine Science, 75(1), 50–60. https://doi.org/10.1093/icesjms/fsx104
- Wong, G., Greenhalgh, T., Westhorp, G., Buckingham, J., & Pawson, R. (2013). RAMESES publication standards: Meta-narrative reviews.BMC Medicine, 11, 20. https://doi.org/10.1186/1741-7015-11-20.
- Young, O. R. (2011). Effectiveness of international environmental regimes: Existing knowledge, cutting-edge themes, and research strategies. *Proceedings of the National Academy of Sciences*, *108*(50), 19853–19860. https://doi.org/10.1073/pnas.1111690108

10. Appendices

a. Appendix 1 – Datasets

CameraGranvin2019

Dato	Laksesmolt
Apr	1
Apr	
Apr	
Apr	1
Apr	4
Apr	4
Apr	
Apr	
Apr	
Apr	
Apr	
May	
May	
May	
May	1
May	1
May	
May	4
May	2
May	6
May	1
May	1
May	3
May	2
May	14
May	30
May	16
May	35
May	7
May	
May	3
May	1
June	
June	3
June	3
June	2
June	2
June	1
June	2

PITOsGranvin2019

Dato	Osvassdrag	Granvinsvassdraget
14.apr	2	
16.apr	2	
19.apr	5	
20.apr	1	1
21.apr	3	1
22.apr	3	
23.apr	8	
24.apr	9	
25.apr	5	
26.apr	3	
27.apr	4	
28.apr	1	
29.apr	3	
30.apr	5	
01.mai	3	
02.mai	4	
03.mai	4	
04.mai	3	
05.mai	6	
06.mai	2	
07.mai	9	
08.mai	4	
09.mai	8	
10.mai	9	
11.mai	1	
12.mai	2	
14.mai	3	
15.mai	2	
16.mai	2	
17.mai	2	2
18.mai		2
19.mai		4
20.mai		9
21.mai		3
22.mai		1
23.mai		1
24.mai		1
26.mai		1
27.mai		2
28.mai		1
30.mai		1
31.mai		2

CameraOs2019

Dato	Laksesmolt
April	1
April	1
April	2
April	4
April	5
April	3
April	7
April	166
April	235
April	80
April	103
April	52
April	66
April	176
April	173
May	95
May	42
May	16
May	30
May	26
May	32
May	13
May	10
May	16
May	14
May	12
May	27
May	31
May	31
May	26
May	19
May	12
May	1
May	11
May	2
May	5
May	3
May	1
May	2
May	1
May	3
May	1

ATOsGranvin 2019

Dato	Osvassdrag	Granvinsvassdraget
April	1	
April	1	
April	2	
April	3	
April	1	
April		1
May	2	
May		1
May	1	
May		2
May	1	
May		1
May	4	
May	2	
May	2	
May		1
May	1	
May		1
May		1
May	1	
May	2	
May		1
May		1
Jun		1

Os2019 – per method

Method	Date	Smolt
PIT	14.apr	2
PIT	16.apr	2
PIT	19.apr	5
PIT	20.apr	1
PIT	21.apr	3
PIT	22.apr	3
PIT	23.apr	8
PIT	24.apr	9
PIT	25.apr	5
PIT	26.apr	3
PIT	27.apr	4
PIT	28.apr	1
PIT	29.apr	3
PIT	30.apr	5
PIT	01.mai	3
PIT	02.mai	4
PIT	03.mai	4
PIT	04.mai	3
PIT	05.mai	6
PIT	06.mai	2
PIT	07.mai	9
PIT	08.mai	4
PIT	09.mai	8
PIT	10.mai	9
PIT	11.mai	1
PIT	12.mai	2
PIT	14.mai	3
PIT	15.mai	2
PIT	16.mai	2
PIT	17.mai	2
Camera	12.apr	1
Camera	13.apr	1
Camera	14.apr	2
Camera	17.apr	4
Camera	18.apr	5
Camera	21.apr	3
Camera	22.apr	7
Camera	23.apr	166
Camera	24.apr	235
Camera	25.apr	80
Camera	26.apr	103
Camera	27.apr	52
Camera	28.apr	66
Camera	29.apr	176
Camera	30.apr	173
Camera	01.mai	95
Camera	02.mai	42
Camera	03.mai	16
Camera	04.mai	30
Camera	05.mai	26
Camera	06.mai	32
Camera	07.mai	13
Camera	08.mai	10
Camera	09.mai	16
Camera	10.mai	14
Camera	11.mai	12
Camera	12.mai	27
Camera	13.mai	31
Camera	14.mai	31
Camera	15.mai	26
Camera	16.mai	19
Camera	17.mai	12
Camera	18.mai	1
Camera	19.mai	11
Camera	20.mai	2
Camera	21.mai	5
Camera	22.mai	3
Camera	23.mai	1
Camera	24.mai	2
Camera	25.mai	1
Camera	26.mai	3
Camera	27.mai	1
AT	22.apr	1
AT	23.apr	1
AT	24.apr	2
AT	26.apr	3
AT	29.apr	1
AT	02.mai	2
AT	07.mai	1
AT	09.mai	1
AT	13.mai	4
AT	15.mai	2
AT	17.mai	2
AT	21.mai	1
AT	25.mai	1
AT	26.mai	2

Granvin2019 – per method

Method	Date	Smolt
PIT	20.apr	1
PIT	21.apr	1
PIT	17.mai	2
PIT	18.mai	2
PIT	19.mai	4
PIT	20.mai	9
PIT	21.mai	3
PIT	22.mai	1
PIT	23.mai	1
PIT	24.mai	1
PIT	26.mai	1
PIT	27.mai	2
PIT	28.mai	1
PIT	30.mai	1
PIT	31.mai	2
Camera	14.apr	1
Camera	20.apr	1
Camera	21.apr	4
Camera	22.apr	4
Camera	04.mai	1
Camera	05.mai	1
Camera	07.mai	4
Camera	08.mai	2
Camera	09.mai	6
Camera	10.mai	1
Camera	16.mai	1
Camera	17.mai	3
Camera	18.mai	2
Camera	19.mai	14
Camera	20.mai	30
Camera	21.mai	16
Camera	22.mai	35
Camera	23.mai	7
Camera	28.mai	3
Camera	29.mai	1
Camera	05.jun	3
Camera	06.jun	3
Camera	07.jun	2
Camera	08.jun	2
Camera	09.jun	1
Camera	15.jun	2
AT	30.apr	1
AT	03.mai	1
AT	08.mai	2
AT	12.mai	1
AT	20.mai	1
AT	23.mai	1
AT	24.mai	1
AT	30.mai	1
AT	31.mai	1
AT	02.jun	1

b. Appendix 2 - R script

```
setwd("C:/Users/Jose de Pool/OneDrive - Nord universitet/Noruega/Master's
Thesis/Datasets") # Where data is stored
install.packages("readxl") #installs package to be able to read excel data
library(readxl) #loads package to be able to read excel data
library(ggplot2)
install.packages("arsenal")
library(arsenal)

#PIT data 2019 and 2020
PITosgranvin2019 <- read.csv("PITOsGranvin2019.csv") #Reads PIT data for Os
and Granvin 2019

#The plot
plot(PITosgranvin2019$ï..Dato,PITosgranvin2019$Osvassdraget,main="Migration
recording on PIT (Os-2019)",xlab="Date of migration",ylab="Number of
salmon",col.main="red",col.lab="blue") #plots date and Os migration 2019
plot(PITosgranvin2019$ï..Dato,PITosgranvin2019$Granvinsvassdraget,main="Migration
recording on PIT (Granvin-2019)",xlab="Date of migration",ylab="Number of
salmon",col.main="red",col.lab="blue") #plots date and Granvin 2019
#The plot

#AT data Granvin 2019 and Os 2019
ATosgranvin2019 <- read.csv("ATOsGranvin2019.csv") #Reads AT data for Os and
Granvin 2019
plot(ATosgranvin2019$Dato,ATosgranvin2019$Osvassdraget,main="Migration
recording on AT (Os-2019)",xlab="Date of migration",ylab="Number of
salmon",col.main="red",col.lab="blue") #plots date and Os migration 2019
plot(ATosgranvin2019$Dato,ATosgranvin2019$Granvinsvassdraget,main="Migration
recording on AT (Granvin-2019)",xlab="Date of migration",ylab="Number of
salmon",col.main="red",col.lab="blue") #plots date and Granvin 2019
#The plot

#Camera data Granvin 2019 and Os 2019
Cameragranvin2019 <- read.csv("CameraGranvin2019.csv")
Cameraos2019 <- read.csv("CameraOs2019.csv")

#The plot
plot(Cameraos2019$Dato,Cameraos2019$Laksesmolt,main="Migration recording on
camera (Os-2019)",xlab="Date of migration",ylab="Number of
salmon",col.main="red",col.lab="blue") #plots Camera data for Os 2019
plot(Cameragranvin2019$Dato,Cameragranvin2019$Laksesmolt,main="Migration
recording on camera (Granvin 2019)",xlab="Date of migration",ylab="Number of
salmon",col.main="red",col.lab="blue") #plots camera dataplot Granvin 2019
#The plot


#PIT AT and Camera data combined
Os2019 <- read.csv("Os2019.csv")
Granvin2019 <- read.csv("Granvin2019.csv")

#LeveneTestOs
library(car)
leveneTest(Smolt~ï..Method,data=Os2019) # Levene's test, F=7.8278,
p=0.0007686
#Significance means the variances are unequal
```

```
#ANOVAOs
res.aov <- aov(Smolt~ï..Method,data=Os2019)
summary(res.aov)
res.aov1 <- aov(log(Smolt)~ï..Method,data=Os2019)
summary(res.aov1)

#Shapiro-WilkOs
resid1=unlist(by(Os2019$Smolt,Os2019$ï..Method,function(x) x-mean(x)))
resid2=unlist(by(log(Os2019$Smolt),Os2019$ï..Method,function(x) x-mean(x)))
shapiro.test(resid1)
shapiro.test(resid2)

#OutlierOs: Might help represent ideal migration conditions
fit0 <- lm(log(Os2019$Smolt) ~ Os2019$ï..Method, data=Os2019)
outlierTest(fit0)

#BoxplotOs: To Illustrate the true difference in variance in amount of
migration between
#the three methods
#notice the use of log in the y axis, meaning I am transforming the data
library("ggpubr")
ggboxplot(Os2019, x = "ï..Method", y = "log(Smolt)",color = "ï..Method",
palette = c("#00AFBB", "#E7B800", "#7570B3"),ylab = "Smolt", xlab = "Method")

#LeveneTest Granvin
leveneTest(Smolt~ï..Method,data=Granvin2019) # Levene's test, F=2.4362,
p=0.09824
#Significance means the variances are unequal

#ANOVAGranvin
res.aov2 <- aov(log(Smolt)~ï..Method,data=Granvin2019)
summary(res.aov2)
res.aov3 <- aov(Smolt~ï..Method,data=Os2019)
summary(res.aov3)

#Shapiro-Wilk Granvin
resid3=unlist(by(Granvin2019$Smolt,Granvin2019$ï..Method,function(x) x-
mean(x)))
shapiro.test(resid3)
resid4=unlist(by(log(Granvin2019$Smolt),Granvin2019$ï..Method,function(x) x-
mean(x)))
shapiro.test(resid4)

#Outlier Granvin: Might help represent ideal migration conditions
fit0 <- lm(log(Granvin2019$Smolt) ~ Granvin2019$ï..Method, data=Granvin2019)
outlierTest(fit0)

#Boxplot Granvin: To Illustrate the true difference in amount of migration
between
#the three methods
#notice y axis is log transformed
ggboxplot(Granvin2019, x = "ï..Method", y = "log(Smolt)",color = "ï..Method",
palette = c("#00AFBB", "#E7B800", "#7570B3"),ylab = "Smolt", xlab = "Method")
```