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TITLE: THE IMPACT OF THE DIFFERENT TREATMENT METHODS, TIME, AND PRODUCTION ZONES ON THE ADULT FEMALE LICE

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ABSTRACT

The aquaculture sector is ever-growing since the 1980s, however, several challenges influence the growth of the industry. One of the core issues is the parasites, named “sea louse”, that attach to the fish and deteriorate the quality and health of the fish. In this master thesis, the longitudinal data extracted from Barents Watch has been used in the empirical studies to analyze the dependence of adult female lice on the cleaner fish, mechanical removal, in-feed, and bath treatment, as well as the time and production zones. Three different regressions are applied to measure the effect of treatment methods. The first regressions suggest that the cleaner fish, mechanical removal, and in-feed treatment methods have a negative impact on the adult female lice at the 10% level of significance, whereas the bath treatment significantly and positively influenced the dependent variable at the 1% significance level. After converting the independent variables for the treatment methods (excluding the cleaner fish) into binary values, the mechanical removal and in-feed became insignificant while the bath treatment maintains its significance and positive effect on the adult female lice. The last regression showed the dependence of adult female lice on the cleaner fish and mechanical removal has been affected negatively and significantly in the random effects GLS regressions. However, the in-feed treatment became once more insignificant and the bath treatment remains a positive and significant impact on the dependent variable. In all the three regression models 13.20% - 14.14% of variation can be explained by these economic models, which indicates that there are other factors that influence the positive effect of bath treatment method or insignificance of in-feed or mechanical removal in some of the models. The time and production zone dummy variables are inserted into the model for each treatment successively. The F-test conducted to investigate the joint significance of all the year regressors and the production zone regressors. The outcome pointed out that both the year and zone regressors are statistically and jointly significant at the 1% statistical significance level.

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Gözde Göktürk

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1. INTRODUCTION

The global Atlantic salmon production increased by 2 million over the years between 1990-2018, from 0.2 million metric tons to 2.2 million metric tons (mt). The top five countries that provide 98% of the salmon production in whole the world are listed respectively: Norway, Chile, the United Kingdom, Canada, and the Faroe Islands (**Figure 1. 1**). In 1990, approximately 0.15 million mt of salmon species supplied by Norway, which was 65.7% of the overall production rate. Despite a couple of decline stages, the amount of production raised slowly but consistently until 2018. This production downturn associated with the disease outbreaks in Chile (Iversen et al., 2020). Furthermore, Forseth et al. (2019) clarified the decrease in the Atlantic Salmon population are mostly occurred in the western and middle parts of Norway and caused due to the harmful activities done by humans, as well as the declining survival rate on the sea and aquaculture activities. In 2018, Norway still has the highest production share in the worldwide by contributing 58% (1.278 million mt.) to overall production (Forseth et al., 2019).

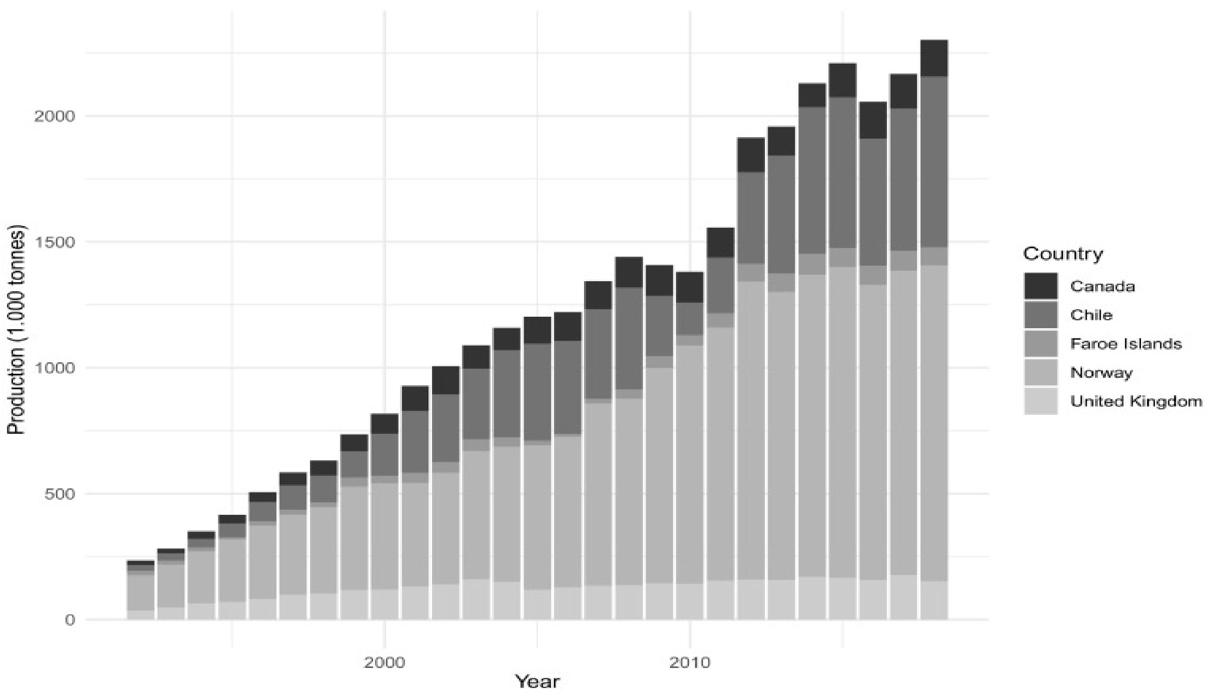

Figure 1. 1: *The production of Atlantic salmon in 1000 tons, 1990-2018. Source: Kontali Analyse AS,* (Iversen et al., 2020)

Norway has the world's most fruitful land due to its long shorelines and abundant marine resources when it comes to Atlantic salmon fishery. Naturally, the aquaculture sector became a significant source of income in the Norwegian economy. The aquaculture adventure in Norway began with nourishing salmons in sea cages by farmers, as a part of the government initiative to tackle the negative effect of decreased wild salmon activities in the late 1960s. However, the real massive production journey started in the 1980s. The aquaculture industry grew sharply after 1985 and continuously expanded (Tilseth et al., 1991). Consequently, this sector had a crucial role in the socio-economical atmosphere. The main social impact of fish farming is to create jobs. According to Finegold (2009), the rate of employment in the aquaculture industry not only increased significantly but it had grown faster than the overall world population. As for Norway, the number of workers in the industry also steadily raised. In 2018, it reached almost 8000 employees which is more than double the number of workers in 1998, 3559 workers (**Figure 1. 2**). He also stated that the production and consumption rate grew simultaneously as a result of urbanization and higher incomes.

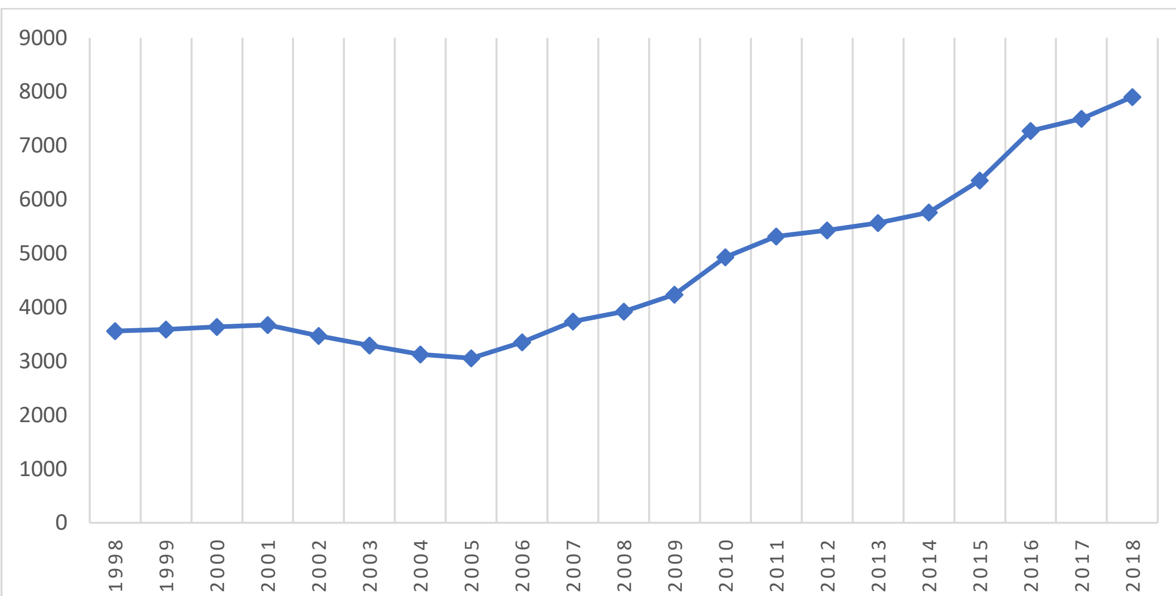

Figure 1. 2: *The number of workers in the aquaculture industry in 1998-2018. Source: Statistics Norway*

Despite the growth in the aquaculture industry, the amount of caught wild Atlantic salmon (Salmo salar) from sea fishing and river fishing has continuously declined over the years, based on Statistics Norway. While the total catch was 1019 tons in 1993, it downsized by approximately

50% and calculated as 583 tons in 2019 (**Figure 1. 3**). Various types of strategies and regulations implemented to increase the number of catches which led to increment in different periods. The dramatic changes in the total catch are linked together with natural ecological processes, and the impact of anthropogenic activities like overfishing, river pollution, and, acid rain. Moreover, the impact of pisciculture operations is considered as the most crucial factor in the wild salmon population (Bergheim, 2012; Liu et al., 2011).

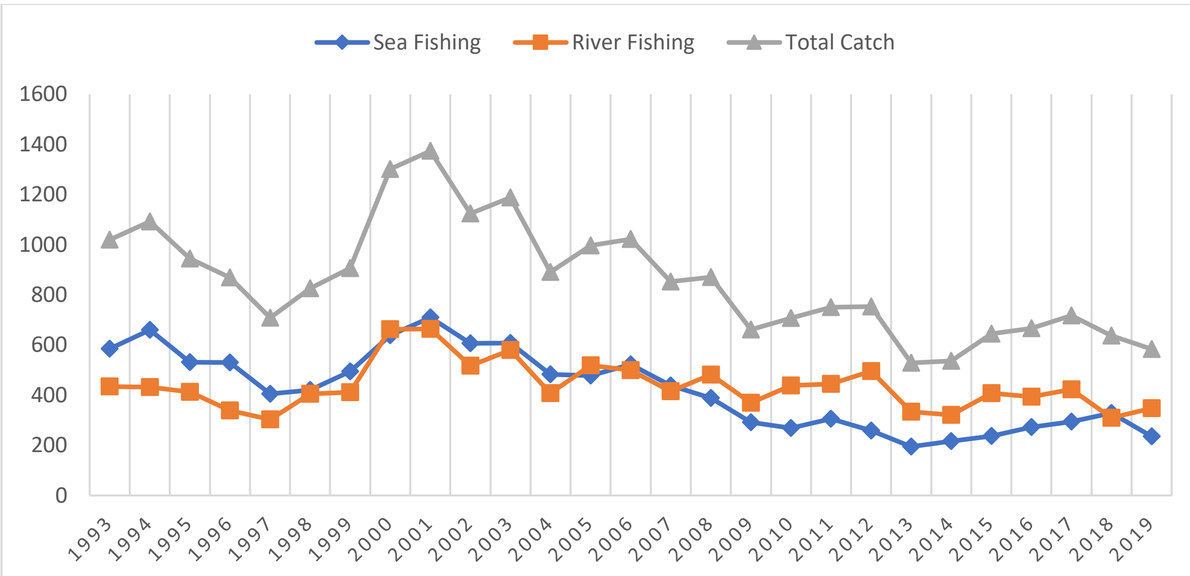

Figure 1. 3: *Wild Atlantic salmon catches from sea and river fishing (in tons), 1993-2019, Source; Statistics Norway*

There are a couple of obstacles and challenges that affect the production of salmons. One of the most important challenges, which is the main subject of this thesis, is the adult female lice. A sea louse is a parasite that tied up to the salmon and deteriorates the health and well-being fish and impairs the quality of inquired salmon species. As a result, high sea lice density do not only react to the fish health and welfare, environment but also the economic impact on both national and regional asset (Costello, 2009). As the both farmed and wild stock increases augments the host abundance for sea lice to attach on, which might lead to the pecuniary loss and intangible damages (Abolofia et al., 2017). In order to stabilize and keep the sea lice density at a certain level, the rigorous and consistent treatment methods are a must. Therefore, there are many treatment methods that have been implemented to keep the concentration of adult female lice. The well-known methods are mechanical removal, in-feed/oral treatment, bath treatment, and usage of cleaner fish. However, there are newly introduced and developing technologies that support aquaculture facilities to stabilize and combat with increasing and spreading adult sea lice population. The new technologies can be named as: offshore cage farming, closed sea cages, land-based on-growing farms, snorkel sea cages.

This master thesis focuses on the four treatments (mechanical removal, in-feed, bath, and cleaner fish) that have been used for a long time. The reasons can be identified as: Firstly, the new technologies are still in the testing phases or just at the beginning of being used, so reaching a data to identify their impact is challenging and not easy to be extracted. Secondly, there is a lot of panel data collection regarding the treatment methods, which are the center of the thesis, thus, it is more reliable to test their impact on the adult female lice. The main contribution of the paper is the empirical analysis of the data regarding the relationship between sea lice concentration and treatments, development over time, and differences between production areas. Thus, this thesis aimed to answer questions that are indicated below:

1) How does each treatment technique can affect the adult sea lice density?
2) Is the time a significant indicator and does it influence the effectiveness of the treatment methods?
3) Do production zones have a different impact on the performance of the treatments?

This paper is divided into 6 chapters. The introduction part gives an insight into an overview of the main topic and the research questions. In chapter 2, it has been provided an extensive literature review and provides an understanding of existing research. This chapter divided into 6 sub-chapters where shed light on important objectives regarding the aquaculture industry. Chapter 3 explains the dataset and the dependent and independent. The method can be found in chapter 4. Next in chapter 5 presentation and analysis of all empirical results can be found. Finally, the last chapter provides conclusion marks and presenting the most important findings.

2. LITERATURE REVIEW

2.1 The Ecology of Atlantic Salmon

A better way to have a clear picture in mind is to understand some of the key biological identity of the Atlantic salmons. The salmo salar species spend all stages of their life in freshwater, mostly located in Norway, Sweden, and Finland. While the young species of salmon is called "Parr", the adult ones that are ready to migrate to the sea are named "Smolt".

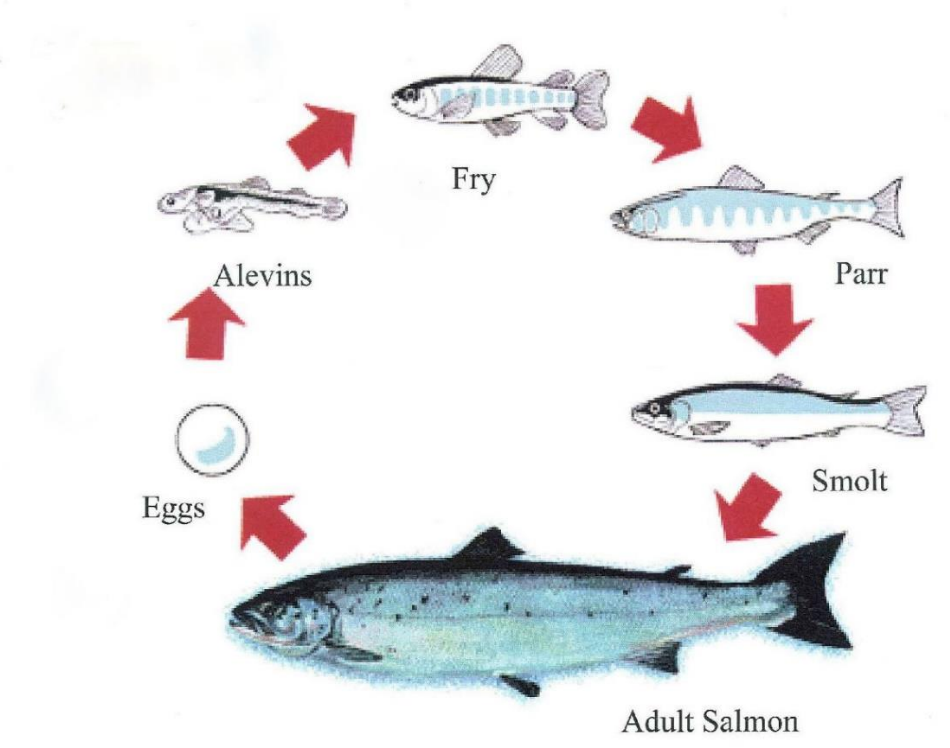

Figure 2. 1: *The life cycle of Atlantic Salmon, Source: Marine Institute*

The Atlantic salmons have to migrate to freshwater to spawn, where the fishes enter the rivers during the Parr period, which is the period of the hatching of their maturity and passing in freshwater stages (Bergman, 2012) (**Figure 2. 1**). The female salmon first chooses a spawning area of adequate size and depth, covered with gravel and with sufficient discharge. The female digs holes at the appropriate depth and laying her eggs, meanwhile, the male fish fertilizes the eggs by leaving their sperms. The spawning process is completed in 2-3 days and the female lays 1100-2000 eggs/kg. The incubation period of the eggs is approximately 440 days-degrees (Hendry &

Cragg-Hine, 2003). The newly hatched Alevin is fed with an egg sac for 3-4 weeks. When the egg sac is pulled, the Fry settles in a cavity between the stones, and the riverbed is protected from the current with minimal energy consumption and starts feeding with zooplankton. Parr spends most of its freshwater life in shallow rivers and oxygen-rich parts. The time to reach the smolt period, when the salmon starts migrating to the sea and gains the ability to live at sea, depends on the length of the summer feeding period. The average age of Atlantic salmon stocks reaching the smolt period is generally 3 years.

2.2 The Challenges in Aquaculture

In this part, the challenges and obstacles in aquaculture and its impact both on the salmonid farming industry and the wild salmon species will be discussed. Based on the studies conducted to examine the effect of aquaculture industry on wild fisheries' production stage concluded that the escapement rate and the sea lice problem are the most critical and significant outcome.

2.2.1 Escape Rate in Fish Farming

When large-scale production began salmon farming suffered from the high escapement rates due to the ruined sea net pens made by external effects such as storms, seals, and otters. After safety investments that strengthen these sea cages put in practice, the unintentional escapement rate reduced. (Olaussen, 2018). The regional Fisheries Directorate reports the escape rate from sea farms using standard reporting forms that are fulfilled by obliged farmers since 1993. In these reports, farmers have to inform the regional directorates regarding the number of escaped salmon, age, health, medication treatment, and the reason for escaping. (Thorstad et al., 2008)

Based on the data derived from Statistics Norway, it is safe to say that the breakdown rate successfully reduced by 360,000 between the period of 1993 and 2018. (**Figure 2. 1**). According to Jensen et al. (2010), the increment of breakout rates explained as a consequence of widened individual salmon farming locations and increased individual sea cages led to a higher rate of escape.

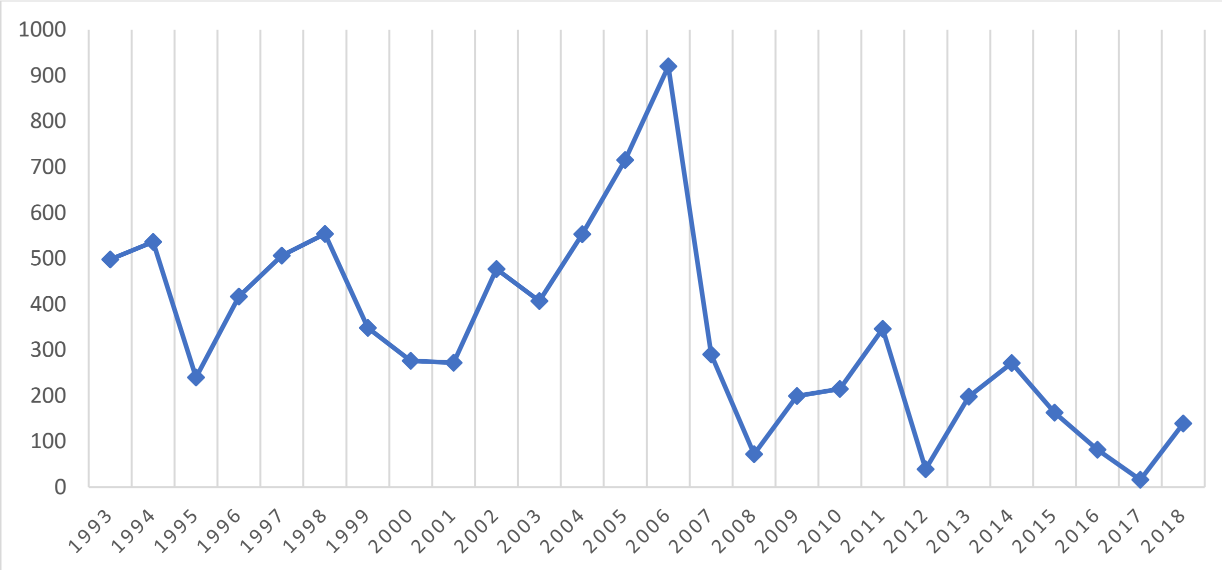

Figure 2. 2: *The escapement rate of salmon between 1993-2018. Source: Statistics Norway*

The escape rates create severe health problems to other local and wild species during different types of interactive activities such as crossbreeding, predation, or colonization which causes the spreading of potential disease and parasite (Olaussen, 2018). The study, conducted by Fleming et al. (2000), has demonstrated that 16% of the wild species are affected by the escapee farmed fished invasion through the introgression stage. However, the severity of the interbreeding implications may vary depending on the number of escapees, historical, adaptive and genetic differences between these species, and the frequency of the invading rate of wild salmons' spawning beds (Glover et al., 2017; Olaussen, 2018). In the long-run, mixed genes evolve the native species capability to adapt to the change in a rapidly changing environment (Glover et al., 2017). According to Olaussen (2018), the escapees from fish farms not only impact the wild species but also impact on the local community by modifying and mutating the habitat and food sources.

2.2.2 Sea Lice

The other threat that wild salmon fisheries face is the high sea lice densities in Norway, which will be the main focus area in this thesis. The parasites which have the biggest impact on the salmon species located in the Atlantic and Pacific are called "Lepeophtheirus salmonis". The salmonid species are affected by these lice during the migration period where they need to move to their winter habitat by using the areas for fish farming (Olaussen, 2018). Some of the empirical studies on these parasites indicated that the mortality and growth of salmons are significantly influenced as the number of salmon farming increases which leads to the rise in lice density (Jonsson & Jonsson, 2004).

The sea lice have several impacts on salmon health and growth. Thorstad & Finstad, (2018) stated that these external parasites feed on the mucous layer, surface, and blood of marine fish and naturally cause damages on Atlantic salmon species. Some of the harms that are led by the lice can be listed as the eroded fins and skin lesions, stress, low resistance against the potential diseases, poor swimming abilities, loss of appetite, slow growth, and behavioral change.

The abundance of *L. salmonis* can change based on the sea temperature, the density, and dispersal of the host. As mentioned before, the increased frequency of the parasites harms both the salmonid farming industry and wild salmon stocks. Several studies carried out to analyze the significance of the distance between two farms as well as farms and wild stocks. The majority of studies find a positive correlation in both cases (Aldrin et al., 2013; Costello, 2006).

In Norway, the average number of sea lice (**Figure 2. 3**) measured 0.22 per fish in 2012. After the drastic fall in 2013, the average number of sea lice per fish increased suddenly in 2014, 0.21. Except for Trøndelag and Møre og Romsdal (TMR), and especially, Hordaland and Sogn og Fjordane (HSF) regions, all the other regions record lower sea lice density than the previous year (Norwegian Food Safety Authority, 2015a). According to the Salmon Lice Report (Norwegian Food Safety Authority, 2015a), the increment in TMR is associated with the increased fish inventory and biomass in the region, which causes high adult female lice concentration, growth in infection pressure, and consequently, more applied treatment to keep lice population under control. In addition, late treatment utilization, and greater demand on the boats and equipment are another reason to trigger the escalation. The highest lice observed in the HSF region, due to the rise in sea temperature. During November and December, the mature sea lice population reached its peak point, this is correlated with the shortage of hydrogen peroxide and deficiency in wellboat capacity. Moreover, the lice had the greatest resistance to pharmaceutical treatment, in particular, emamectin benzoate.

Excluding the year 2014, the number of adult female lice on average dropped. The lowest number was recorded in 2018, which is 0.14 lice on average per fish. Even though the significant decline over the years, it can be seen that the sea lice concentration is higher than the targeted number, 0.1.

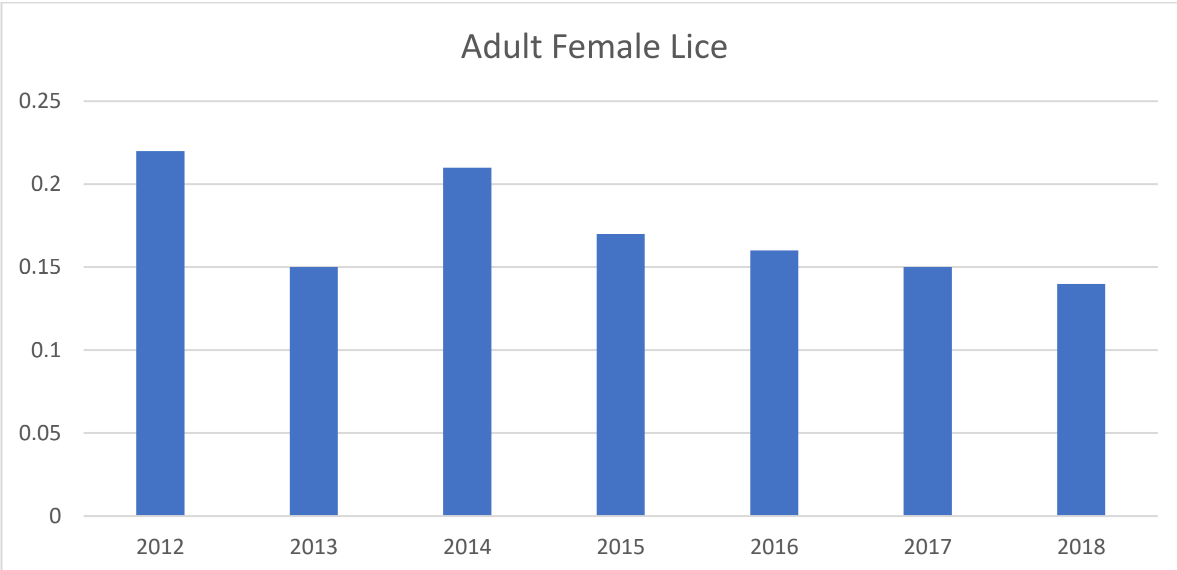

Figure 2. 3: *The average number of sea lice per fish. Source: lusedata.no*

2.3 The Aquaculture Licensing and Regulations in Norway and the Traffic Light System

The sea lice problem in Norway triggered several government regulations and licensing restrictions in order to sustain growth in the aquaculture value chain and protect the fish's health and welfare. The licensing for fish-farming authorizes fish farming production in both the freshwater with no limitations and the seawater with a restriction of 1041 tons. The licenses are issued by the Norwegian Ministry of Trade, Industry, and Fisheries in certain times, and controlled by the Directorate of Fisheries.

The location and technology-oriented experiments on salmon fed in the fish farming nets led by small-scale farmers laid the foundations of the regulations in the Norwegian Aquaculture Industry, in the 1960s (Aarset & Jakobsen, 2009). However, the regulations were not good enough to promote salmon farming, because at the time aquaculture was disregarded as a source of income for the nation. In 1973, the Aquaculture Act came to force and the Ministry of Fisheries is held accountable for the sea farming industry. The first act gave all required permissions to most of the applicants to start sea farmers. The second act introduced with restrictions on the granted permissions in 1981. The act was limited to create and protect the industrial-based business model. The third Aquaculture Act was approved in 1985, however, it performed poorly due to the decline in salmon prices, and unstable production processes (Aarset & Jakobsen, 2009; Olaussen, 2018). During the 1990s, the regulations suffered from two main shortcomings: lack of comprehension of market observations, fall of prices due to come up short against the managing of supply shocks. In this period, one of the important changes occurred and the small-scale farmers give place to larger companies.

According to Olaussen, (2018), in 2005 the sustainable development and steady growth were the primary targets to follow in the fish farming industry. The 2005 Aquaculture Act, as well as the Food Safety Act, still is considered as the most significant law in the sector. The total number of producing salmon in sea farms restricted to 200,000 per cage with maximum allowance biomass of 780 tons per license, whereas 945 tons in Troms and Finnmark, in 2013. In addition, several more policies are taken into account to strategically deal with sea lice problems such as regular sea lice reports. Furthermore, if the density of adult female lice is over 0.2 on average during the migration period, and below 0.5 rest of the season, interferences are required to lower the ratio, based on the legislation (Aarset & Jakobsen, 2009; Olaussen, 2018). In 2015, the White Paper introduced in the parliament and largely accepted by the members. Norwegian Ministry of Trade (2015), announced that sea lice will be used as a proxy to adjust capacities in the aquaculture sector, in the short- or medium-term. Moreover, the Norwegian government created a new type of license to encourage the application of new technological enhances (Mowi, 2019).

The Norwegian regulations regarding battling with salmon lice in fish farms require every farm to collaborate with the other farms in the same area to form solid and efficient plans to control sea lice problem (Norwegian Ministry of Trade, Industry and Fisheries, 2012). The acceptable plan has to offer an insight into any of the following information:

a. The name, the location number, and contact details of the salmon farms.
b. The rationale behind selecting the stated location
c. Implemented methods to keep lice under control
d. The details regarding treatment methods such as periods, type of technique

e. Structure of the systematical knowledge exchange between the aquaculture facilities, stating the finalized treatment procedures, the number of sea lice in the facility.

Moreover, the Norwegian Food and Safety Authority obliged each facility to report no later than Tuesday in the following week (Norwegian Ministry of Trade Industry and Fisheries, 2012). The followings must be indicated:

a. seawater temperature,
b. the applied lice treatment,
c. the active substance and the amount of active substance used,
d. sensitivity tests results,
e. suspicion of resistance,
f. the number of adult female lice, moving, and trapping stages.

The government issued a new type of regulation in October 2017, named as “Traffic Light System (TLS)” (Svendsen, 2019). The regulation scheme stands for the creation of production areas and capacity for each zone to maintain environmental sustainability in the aquaculture industry while increasing profitability and gaining a competitive edge (Ministry of Trade and Industry, 2017; Svendsen, 2019). The TLS divides Norway into 13 different production zones using environmental indicators[1];

1. The Swedish border to Jæren,
2. Ryfylke,
3. Karmøy to Sotra,
4. Nordhordland to Stadt,
5. Stadt to Hustadvika,
6. Nordmøre and South-Trøndelag,
7. North Trøndelag including Bindal,
8. Helgeland to Bodø,
9. Vestfjorden and Vesterålen,
10. Andøya to Senja,
11. Kvaløya to Loppa,

[1] The indicator uses the sea lice density on salmon species.

12. West Finnmark,
13. East Finnmark.

The map of the 2017 traffic light system showed in **Figure 2. 4**. The government assigned 8 zones as green, 3 zones as yellow, and 2 zones as red. This means the green marked areas can be able to increase their production capacities 6%, while the yellow zone has to keep and continue as before, and the red zone is required to downsize the production are if not meet the requirements that are assigned by the government.

Furthermore, the Ministry is entitled to downgrade, refrain or increase the production capacity if the production zone does or does not meet the required environmental criteria. However, the Ministry still might offer additional capacity, maximum 6%, for the production facilities regardless of environmental status indicators as well, if the license holder:

- documents non-released sea lice larvae in mass water in a year.
- has no more than 0.1 sea lice per fish in 6 months and uses only one treatment for less than a year. However, the Ministry grants for those who have more than 0.1 adult female lice unless it detected more than three successive counts within the defined period (Ministry of Trade and Industry, 2017).

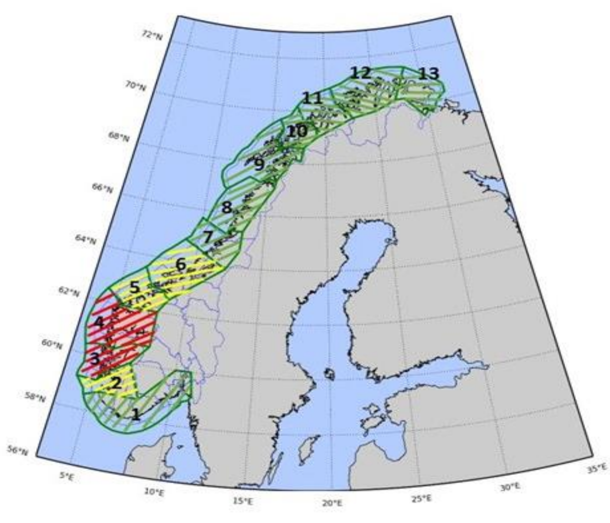

Figure 2. 4: *The map for the 13 production areas. Source: regjeringen.no*

2.4 The Life Cycle of Salmon Louse

The salmon louse, *Lepeophtheirus salmonis*, is small aquatic crustaceans that are indigenous parasites to salmonid species such as *Salmo, Oncorhynchus and Salvelinus* (Byrne et al., 2018; Costello, 2006; Hamre et al., 2013) In this context, it is noteworthy to comprehend the ecology of sea lice.

The life cycle of the salmon louse contains ten stages except for the hatching stage (**Figure 2. 5**). All the first three stages are non-feeding and non-parasitic. The adult female lice can produce more than 10 egg strings, every string is a host for between 100-1000 eggs, during its lifespan (Byrne et al., 2018). The female carries the eggs on long traces and lays them under suitable conditions, then turns into Nauplius I where the egg strings are separated and became a planktonic larval. The term planktonic used for the nonmobile species that are too small or weak to swim against the current. All the energetic activities are done by the female lice, during the vitellogenesis and pre fertilization maturation phase (Revie, 2009). After Nauplius, I stage, the Nauplius II stage begins. These two nauplius stages last 5-15 days.

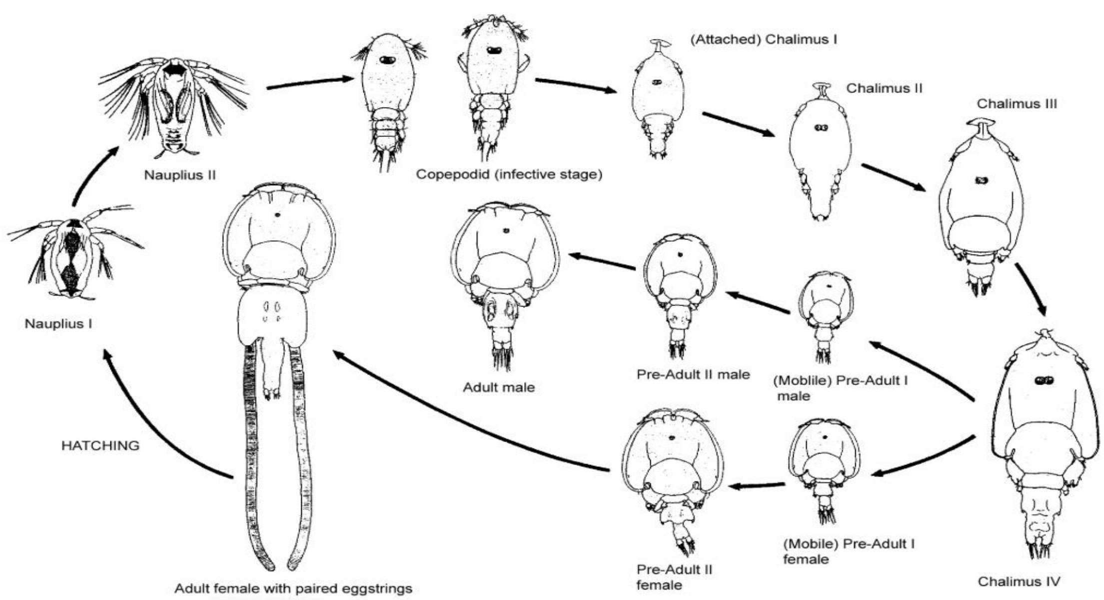

Figure 2. 5: *The life cycle of sea louse. Source: Revie, C. (2009). Sea lice working group report.*

The third and last mobile stage is called the “Copepodid stage”. The growth of the lice depends on the temperature throughout different stages. The high salinity content rate in seawater is the optimum level for the sea lice to survive and radiate faster which demands the salinity of 30 PSU[2] or more (Byrne et al., 2018), and salmon louse dies immediately after exposure to freshwater. According to the several empirical studies stated that the infective free-living copepods can distinguish the shadow and the scale of hosts, sense vibrations using mechanoreceptors that created by hosts, and detect the favorable hosts through chemoreceptors (Costello, 2006).

The copepod molts into the first frontal filament[3] stage, Chamilus, which goes through four stages in a row. In this stage, the chalimus larvae attach to the fish and stay immobile. According to Hamre et al. (2013), there are not so many differences between Chalimus I and II, as well as Chalimus III and IV. They stated that chalimus differ in size and the degree of development of certain limbs during these stages. The chalimus larvae are then transformed into pre-adult I and II stages. Finally, pre-adult II then becomes an adult sea louse that can be seen with the naked eye and develops (Byrne et al., 2018; Costello, 2006; Revie, 2009). The adult female sea lice are larger than the males and leave long traces. The early and adult phases of sea lice cause maximum death for the salmons. Their lifetime of a louse can vary from 6 to 8 weeks, depending on the species.

2.5 The Treatments of Sea Lice

The problem of sea lice has a huge impact on salmon productivity. Therefore, there are a couple of delousing methods to their abundance rate among the seawater such as chemical, mechanical, biological, and oral treatment activities. This paper focused more on the following treatments: the temperature and mechanical removal, the cleaner fish, the bath, and finally in-feed.

[2] Practical salinity units
[3] Slender threadlike in a form of fiber

2.5.1 The Thermal Treatment and Mechanical Removal

The temperature de-licing is one of the methods to fight against increasing of lice abundance. The thermal treatment was encouraged because the majority of studies stated that medicament usage developed the ecological resilience and adaptability of the louse (Grøntvedt et al., 2015; Olaussen, 2018). According to conducted experiments and studies, salmon species can tolerate between the 20-34˚C temperature of the water for a short time. When the infected fish exposed to warm water, it has observed that sea lice began to separate from the host. The salmonids, as well as sea lice, do not have high physical endurance against high-temperature water. However, due to the size differences fish have higher chances of survival in comparison with *L.salmonis* (Grøntvedt et al., 2015; Overton, Dempster, et al., 2019).

In Norway, the treatment applications have to be tested and approved if the new solution techniques meet the requirements and necessary qualifications before they can be used. After the legislation approval, Thermolicer mechanical removal machines, which are built and designed by a Norwegian company, are an innovative technical method to de-lice salmon (Grøntvedt et al., 2015). These machines use warm, cold seawater, or heated freshwater with adjustable temperature features. The mechanical delousing treatments are non-medical and non-chemical applications. The Thermolicer machine works as follows (**Figure 2. 6**); the infected salmon species are pumped from the sea cage (1) and bathed in water strainer to purify from the seawater (2), where the seawater left out of the system (3). Then the fish is exposed to lukewarm water (4) and proceeds through the treatment reservoirs (5,6). After the delousing phase, the fish is removed from the treatment water (7) and released from the system (8). Finally, the used lukewarm water moves back to the tank, where it is filtered, aerated, and reheated (9), to be used in the process again (10).

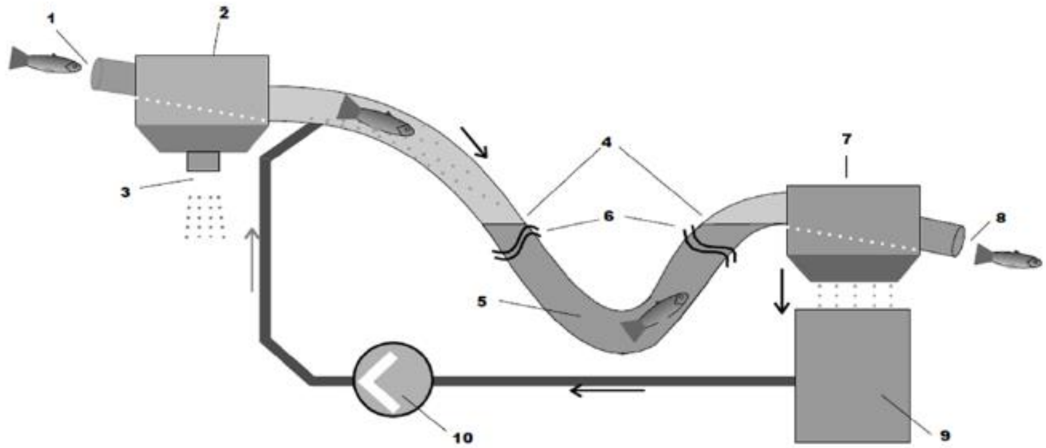

Figure 2. 6: *Schematic diagram of the Thermolicer. Source: Grøntvedt, R. N., Nerbøvik, I.-K., Viljugrein, H., Lillehaug, A., Nilsen, H., & Gjvre. Anne-Gerd. (2015). Thermal de-licing of salmonid fish - documentation of fish welfare and effect. Norwegian Veterinary Institute`s Report Series, 13(January), 34.*

Overton, Oppedal, et al. (2019), conducted an experimental study to understand the effect of the cold water on comping with sea lice problems. The study was carried out using 320 post-smolt species and locally sourced egg strings that are cultivated and incubated until they reach the chalimus phase. Also, each fish was infected by 11 parasites, on average, 6 times with a duration of 7-week time. The fish exposed to a cold-water temperature of -1, 1 or 5˚C, on two different time intervals, 0.5-10 minutes, and 30-240 minutes. The result showed that the density of sea lice was lowest when the fish stayed in minus 1˚C for 10 minutes. While no changes observed for the abundance of fixed lice, the lowest density for mobile lice had seen on fish groups which treated cold-water of minus 1˚C for 10 minutes 1˚C for 240 minutes.

Gismervik et al. (2019) researched hot-water experiments and its effect on salmon health and welfare. The Atlantic salmonid smolts are moved to the treatment tank where they become subject to various temperatures until the point in which they are euthanized. The smolts experienced a temperature of 34-38 ˚C and as a result, they faced several injuries such as soft tissue injuries, bleedings, congestion. The study indicated that higher water temperature decreases the survival rate, and gill injuries are the primary cause of thermal de-licing methods.

2.5.2 The Medicinal Treatment

The pharmaceutical treatment application methods are divided into two different techniques: in-feed or oral and bath treatment. As the sea lice develop resistance to drug treatment, consequently, the usage of medicinal method diminishes as the non-medical becomes a more preferable and effective technique against sea lice on salmon species (Rueness et al., 2019).

2.5.2.1 The In-Feed (Oral) Treatment

Controlling lice through oral treatment applications are diminished over the time due to the new technologies such as closed plants, offshore fish farming, etc. and high demand for non-chemical alternatives like skirts, cleaner fish, mechanical removal. (Norwegian Institute of Public Health, 2019) Nevertheless, the in-feed treatment still is an accurate treatment method in Norway.

The medicaments and antibiotics that are used in-feed treatment methods are diflubenzuron, emamectin benzoate, teflubenzuron, florfenicol, oxolinsyre, and oxytetracycline. The active substances like acylureas[4] and emamectin are more common in comparison with the antibiotics (**Figure 2. 7**). According to BarentsWatch, fish cannot digest antibiotics and release them into nature through urine and feces, this might be the reason behind less antibacterial remedy utilization. Thus, the overall graph of remedies for in-feed treatment demonstrates the decreased consumption of drugs. The first graph shows that diflubenzuron is used more frequently between 2011-2018. It reached its peak point in 2015 where it doubled the sale of emamectin. As for the sales of antibiotics points that florfenicol and oxolinsyre are widely used remedies than oxytetracycline. Comparing the sales of florfenicol a year before, florfenicol was sold more in 2018. The Norwegian Veterinary Institute (2019) explains the sudden rise due to the increased average weight of the fish in all types of fish farms.

[4] Diflubenzuron and teflubenzuron

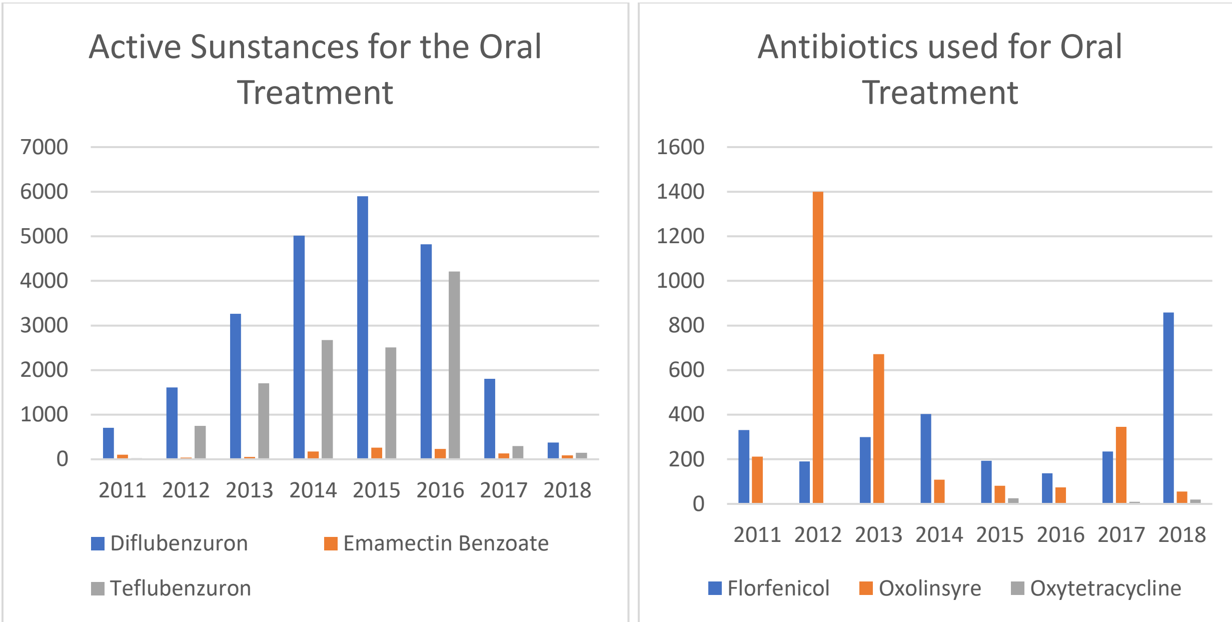

Figure 2. 7: *The sales of pharmaceuticals (in kg) used for in-feed treatment between 2011-2018 Source: barentswatch.no*

2.5.2.2 The Bath Treatment

The bath submergence is another technique that is used by farmers to clear salmon species from any ectoparasites. The pharmaceuticals that are mostly used in bath treatment applications are respectively hydrogen peroxide, azamethiphos, deltamethrin, and cypermethrin in Norway. In **Figure 2. 8**, the four graphs represent the consumption of these four substances. The usage of these active substances declined from 2011 through 2018. There are many cases where the sales of the substances increased. These are mainly the years where the sea lice density was higher (2012 and 2014). According to (Norwegian Food Safety Authority, 2015b), the resistance of lice against the azamethiphos, cypermethrin, and deltamethrin increased however, a higher mortality rate recorded while hydrogen peroxide is used during the de-lousing methods. The sudden increase in hydrogen peroxide can be seen in 2015.

Overall, the most common active substance that is used in the aquaculture industry is hydrogen peroxide and then azamethiphos. However, the usage of all the pharmaceutical reduces over the years.

The bath treatment might occur either on wellboats and sea cages contingent on the pesticide. The de-lousing process on the wellboats is time-intensive, costly, and labor-intensive procedures, the total quantity of organisms in the area is the determinant for the wellboats utilization (Corner et al., 2011; Norwegian Medicines Control Authority, 2000). The maximum loading cargo capacity for wellboats is 100 tons, and the length of the treatment period varies from 30 minutes to 60 minutes. The health and welfare of fish may be damaged during the loading and unloading processes; however, the vacuum pump technique reduces such injuries. Another factor that effects fish welfare is the risk of catching winter ulcers due to the temperature differences between wellboats and seawater.

There are two types of bath treatments in the sea cages, which are called tarpaulin enclosure or closed system and so-called skirt method or open cage. There are several factors that influence the oxygen demand for fish: the size of the cage, the biomass of the fish, water temperature, and the wave velocity. These factors have an impact on choosing these procedures (Norwegian Medicines Control Authority, 2000). In theory, the tarpaulin enclosure is more optimal in comparison with the skirt method due to its volume, easily controlled oxygen level, and drug use. However, in practical terms, it is not the ideal solution. The bath treatment methods require new and better technological solutions in order to solve the risk and high mortality challenges.

2.5.3 The Cleaner Fish

Even though mechanical and thermal treatment methods are the most common two delousing applications, the significance of less stressful approaches on fish such as cleaner fish techniques, cannot be neglected. The commercial utilization of wild-caught cleaner fish initiated in 1988, and gained acceleration after 2012, due to the acclimation of sea lice to the medical treatments (Barrett et al., 2020). The species that are used as a cleaner fish, starting from the most used to the least, are lumpfish (Cyclopterus lumpus), goldsinny wrasse (Ctenolabrus rupestris), corkwing wrasse (Symphodus melops), Ballan wrasse (Labrus bergylta), and cuckoo wrasse (Labrus mixtus) (**Figure 2. 9**). The usage of cleaner fish continued to increase during 2015-2017. However, it began to decline and measured as approximately 50 million at the end of 2018.

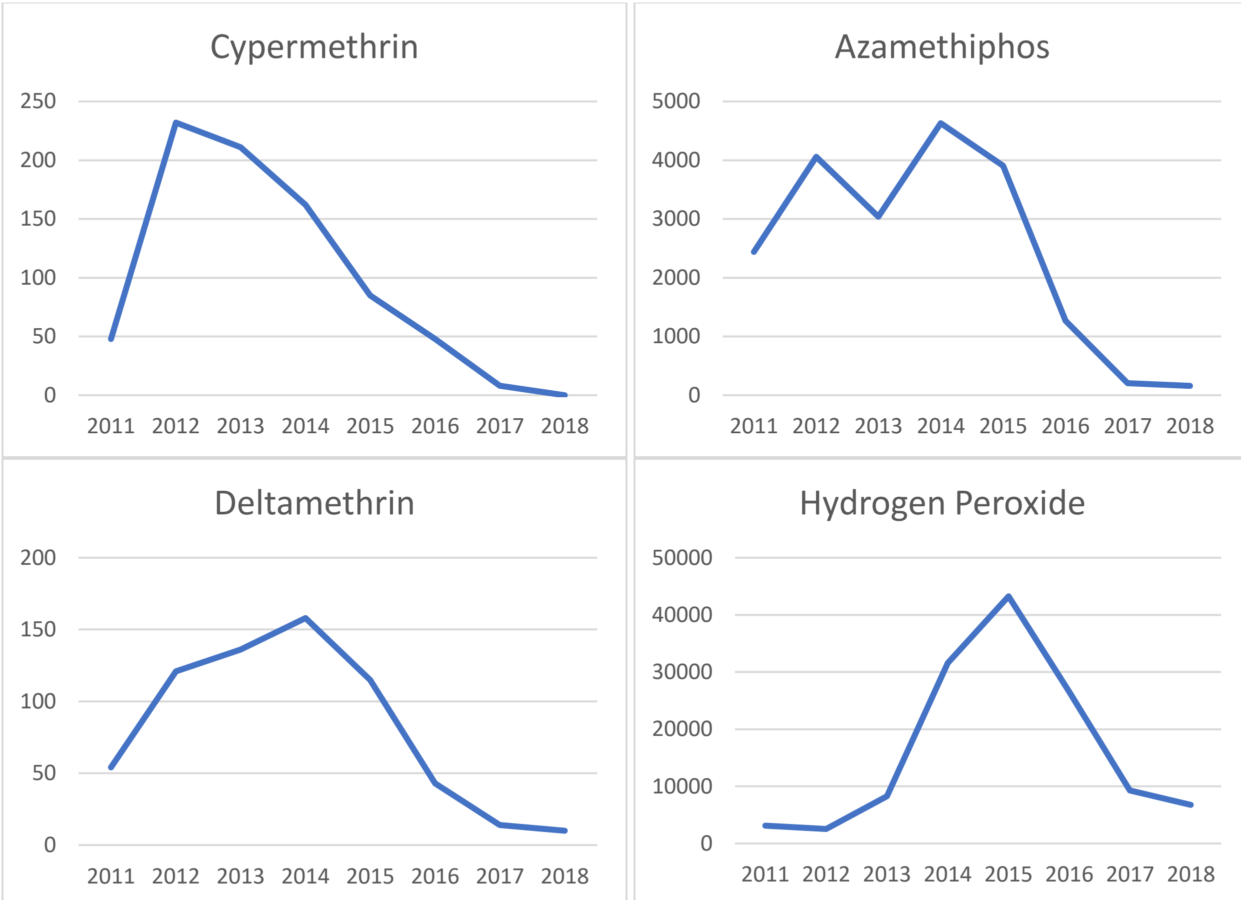

Figure 2. 8: *The sales of four medicaments used for bath treatment between 2011-2018. Cypermethrin, Azamethiphos, Deltamethrin are shown in kg, whilst hydrogen peroxide in ton. Source: barentswatch.no*

The majority of lumpfish species are bred in the incubator, while the wrasses are both caught in the wild and produced. The reason why wrasse is wild-caught is that the challenges encountered as a consequence of the length of the production stage that takes up to more than a year, whereas the generation time for the lumpfish 60% shorter in comparison. As a result, lumpfish is the most popular animal that is used to war with sea lice growth in Norway because the species can survive lower temperatures than wrasses (Barrett et al., 2020; Bolton-Warberg, 2018). Nevertheless, the Ballan wrasse species has fewer mortality rates and are qualified as the best species to de-louse the salmon (Rueness et al., 2019).

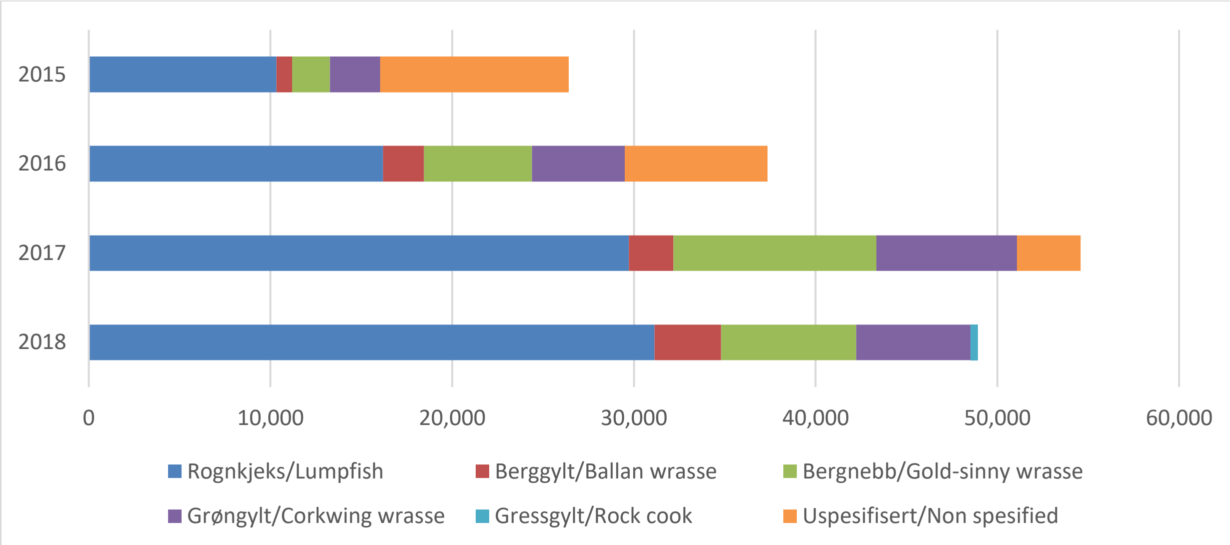

Figure 2. 9: *The number in 1000 individuals of cleaner fish usage by species between 2015-2018. Source: Norwegian Directorate of Fisheries*

Although the cleaner fish methods have fewer hazards on salmon species, the treatment has ethical considerations regarding the welfare of cleaner fish and genetic impact on wild cleaner fish populations (Rueness et al., 2019). Furthermore, the wild wrasse, which is caught by small boats, are delivered to the fish farms via boats or trucks from British Isles (Halvorsen et al., 2017; Rueness et al., 2019). However, the duration of the journey deteriorates the well-being and quality of the fish. In addition, the cleaner fish that are stuck in sea cages suffer from less survival rate due to poor health conditions led by biological factors like stress, feeding disorder, or external sources such as high currents, warmth (Barrett et al., 2020). Moreover, cleaner fish consume dead skin and external parasites, but feeding on sea lice is an acquired behavior among the cleaner fish species. They have to respond behaviorally to the change of nutrition under a controlled environment. However, the species might able to be nourished on alternative sources and stop consuming the salmon lice.

The Norwegian Directorate of Fisheries made regulations in 2019 for the cleaner fish and set limitations on both sizes for each species as prevention for potential escapes from sea cages, and the total amount of cleaner fish (max 18 million,) that can be caught in the wild (Halvorsen et al., 2017; Rueness et al., 2019).

3. DATA

The secondary data associated with sea lice density on this empirical study is collected from BarentsWatch[5]. This large-scale historical data reports several vital variables relevant to this master thesis such as the adult sea lice concentration, the treatment methods, the salmon population, and the biological features of the salmon in different production zones. The study includes all the active aquaculture firms in Norway. The original dataset covers all the weeks between 2012-2018. The original data collection has 394063 observations however, it aggregated monthly.

Table 3. 1 shows all the names and descriptions of variables that are used in this master thesis. The variable to measure average biomass is added, dividing the number of the fish in each farm inventory at the end of the year with their biomass in kg. The mobile lice binary variable is appended to measure the impact of the ice outbreaks on sea adult female lice. The mechanical removal, in feed and bath variables dummy variables are included for each application, which explains if any of these methods applied in the farms. In addition, several zero-one variables are created to measure the singularity effect of each year and the production area. Thereby, 6 binary variables representing the year between 2012-2018, as well as 12 dummy variables portraying the 13 production zones are formed.

The longitudinal dataset consists of the month range from January 2012 to December 2018, 84 months in total. The number of observations in the original dataset, in total, is calculated as 51904 however, 4240 observations are eliminated due to no available data regarding adult female lice density. Furthermore, there are 5818 cases, where no value on what kind of treatment method was implemented, are deleted. And finally, 1430 observations with 0 biomass and 17 observations with no production area defined are removed. Therefore, 40699 observations are taken into consideration when the analyses were regressed.

[5] An organization that gathers information on sea lice, fish diseases in the aquaculture industry on a weekly basis. The data derived from https://www.barentswatch.no/en/download/fishhealth/lice

variable name	storage type	display format	value label	variable label
adultfemalelice	float	%8.0g		mean adult female lice.
cleanerfisht	float	%9.0g		average number of cleanerfish (in tonnes)
mechanical_re~1	float	%9.0g		Number of weeks that the mechanical removal treatment was performed: 1-5 weeks
medicine_feed_1	float	%9.0g		Number of weeks that the medicine feed treatment was performed: 1-5 weeks
medicine_bath_1	float	%9.0g		Number of weeks that the medicine bath treatment was performed: 1-5 weeks
mechanical_re~l	float	%9.0g		dummy variable. mechanical_removal = 1 if there is mechanical removal treatment
in_feed	float	%9.0g		dummy variable. in_feed = 1 if there is in feed treatment
bath	float	%9.0g		dummy variable. bath = 1 if there is bath treatment
avg_bio	float	%9.0g		average fish biomass (in kg) in the fish farm ath the end of the month
mobile_lice	float	%9.0g		dummy variable. mobile_lice = 1 if there is a adult female lice
year12	float	%9.0g		year = 2012
year13	float	%9.0g		year = 2013
year14	float	%9.0g		year = 2014
year15	float	%9.0g		year = 2015
year16	float	%9.0g		year = 2016
year17	float	%9.0g		year = 2017
prodar1	float	%9.0g		productionarea_n = 1
prodar2	float	%9.0g		productionarea_n = 2
prodar3	float	%9.0g		productionarea_n = 3
prodar4	float	%9.0g		productionarea_n = 4
prodar5	float	%9.0g		productionarea_n = 5
prodar6	float	%9.0g		productionarea_n = 6
prodar7	float	%9.0g		productionarea_n = 7
prodar8	float	%9.0g		productionarea_n = 8
prodar9	float	%9.0g		productionarea_n = 9
prodar10	float	%9.0g		productionarea_n = 10
prodar11	float	%9.0g		productionarea_n = 11
prodar12	float	%9.0g		productionarea_n = 12

Table 3. 1: *The description of the variables*

The number of the observations, mean values, standard deviations, minimum and maximum values of the variables is illustrated in **Table 3. 2**. In the table, the mean for adult female lice is measured as 0.175 which is higher than the required sea lice level for authorities to accept increasing the capacity for salmon production (Ministry of Trade and Industry, 2017). Moreover, the standard deviation of the adult female sea lice, 0.35 suggests that observations are spread out over a large range of values and far away from the mean. This means that the farms that suffer from the lice epidemic are much greater than the average number of adult female lice.

Variable	Obs	Mean	Std. Dev.	Min	Max
adultfemal~e	40,699	.1754244	.3509918	0	9.467999
cleanerfisht	40,699	4.153182	10.76737	0	184.39
mechanical~1	40,699	.9413253	1.769647	0	5
medicine_f~1	40,699	.5832576	1.458777	0	5
medicine_b~1	40,699	1.755473	2.117886	0	5
mechanical~l	40,699	.2343301	.4235846	0	1
in_feed	40,699	.1472518	.3543611	0	1
bath	40,699	.4257844	.4944674	0	1
avg_bio	40,699	2.337257	2.011932	-1.855	18.336
mobile_lice	40,699	.8038527	.3970862	0	1
year12	40,699	.1315757	.3380331	0	1
year13	40,699	.1348682	.3415869	0	1
year14	40,699	.1425834	.3496518	0	1
year15	40,699	.1437382	.3508284	0	1
year16	40,699	.1450158	.3521211	0	1
year17	40,699	.1475221	.3546299	0	1
prodar1	40,699	.0132681	.1144221	0	1
prodar2	40,699	.0596083	.2367627	0	1
prodar3	40,699	.1902749	.3925228	0	1
prodar4	40,699	.1528784	.3598747	0	1
prodar5	40,699	.052188	.2224087	0	1
prodar6	40,699	.1590211	.3657003	0	1
prodar7	40,699	.0575198	.2328361	0	1
prodar8	40,699	.0920661	.2891229	0	1
prodar9	40,699	.0794123	.2703845	0	1
prodar10	40,699	.0588467	.2353404	0	1
prodar11	40,699	.029411	.1689578	0	1
prodar12	40,699	.0540554	.2261297	0	1

Table 3. 2: *The descriptive statistics of the overall data that are used in the analysis.*

4. METHODOLOGY

This chapter characterizes the methodology and the procedures applied to attain the objectives of the research. This master thesis is established upon the quantitative analysis method, specifically econometric analysis. The analysis aims to analyze the impact of each treatment technique, those are mechanical removal, in-feed, bath, and cleaner fish, in conjunction with the average biomass of the fish and whether the farm experience with lice outbreaks on adult female lice concentration. In addition, time can be another indicator that might affect lice density due to technological developments over the years between 2012-2018. Moreover, the production and capacity are divergent in each production zone. Therefore, time and production zones factors are implemented successively to the economic model to test their influences.

Briefly, 19 regressions on STATA are run in the economic model basing the adult sea lice as a dependent variable. Each treatment method is tested as indicated below:

1. Without time and production areas
2. With time only
3. With time and production areas

The economic model that are used in this model, is shown below:

$$adult\_female\_lice = \beta_1 treatment\_method + \beta_2 avg\_biomass + \beta_3 mobile\_lice + \gamma_1 year12 + \gamma_2 year13 + \gamma_3 year14 + \gamma_4 year15 + \gamma_5 year16 + \delta_1 prodar1 + \delta_2 prodar2 + \delta_3 prodar3 + \delta_4 prodar4 + \delta_5 prodar5 + \delta_6 prodar6 + \delta_7 prodar7 + \delta_8 prodar8 + \delta_9 prodar9 + \delta_{10} prodar10 + \delta_{11} prodar11 + \delta_{12} prodar12$$

Thereby, the following hypotheses are tested:

Hypothesis I: The objective is to compare the impact of each treatment method. Since these application techniques are developed to reduce the lice population, it is expected to have a negative influence on the adult female louse. Four different hypotheses tested:

H_0: *cleanerfisht* < *0*	H_0: *mechanical_removal* < 0	H_0: *in_feed* < 0	H_0: *bath* < 0
H_1: *cleanerfisht* ≥ *0*	H_1: *mechanical_removal* ≥ 0	H_1: *in_feed* ≥ 0	H_1: *bath* ≥ 0

Hypothesis II: As technology enhances over the years, each year will have different influences. The following hypothesis is tested for each treatment technique:

H_0: $\gamma_1 = \gamma_2 = \gamma_3 = \gamma_4 = \gamma_5 = 0$

H_1: *H_0 is not true*

Hypothesis III: Each zone will have a different effect on adult female lice due to different production capabilities. The hypothesis that is tested for all the treatments is indicated below:

H_0: $\delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = \delta_6 = \delta_7 = \delta_8 = \delta_9 = \delta_{10} = \delta_{11} = \delta_{12} = 0$

H_1: *H_0 is not true*

5. ANALYSIS AND RESULTS

After the data preparation, the economic models are structured, and regressions are concluded. This chapter provides the results of the analyses of these models and gives insight into the hypothesis. Furthermore, based upon the residuals vs. predictor plot graph, models are tested (see Appendix A, **Figure 8. 1**) for heteroskedasticity using the Breusch-Pagan test in the analysis. Since the Prob > chi2 = 0.0000 for each regression, this signifies heteroskedasticity in all the econometric models. Therefore, the robust standard errors applied to each regression.

Hypothesis I: Using STATA 16.0 software, the first hypothesis has been tested to analyze the impact of each treatment methods on adult female lice. Each of the treatment method is significant at the 10% significance level while the cleaner fish and bath treatment techniques are significant both 5% and 1% levels of significance (***Table 5. 1***). Using a t-test to analyze hypothesis I for the cleaner fish, the mechanical removal, and the in-feed treatment techniques, the null hypotheses are failed to reject, while hypothesis I is rejected for the bath treatment. So, all four treatments excluding the bath treatment have a negative impact on the adult female lice. The cleaner fish has the most negative influence on adult sea lice than any other application.

14% of the variation in adult female lice can be explained by the economic model that we used for the bath treatment. In other words, there might be other factors that are not included in the model might influence the negativity on lice density, such as timing effect: when both the dependent and independent variable were measured. Each of the regression for the Hypothesis I also suggests that average biomass and the existence of lice in fish farms have a positive impact on the adult female sea lice, which appears to be reasonable. As the density and dispersal of the host increases, there will be higher chances for lice to attach to the fish. If the aquaculture facility experience lice outbreaks, it indicates that the concentration of the adult female lice tends to increase in population as well and pressure on the wild salmon stock.

Later in the model, the zero-one variables are included for each treatment excluding the cleaner fish variable, imply that whether mechanical removal, in-feed, and bath treatment implemented at the farm, to see if there is any difference in the outcome. The base group for these treatment applications represents that there is no treatment applied in the farm and no outbreaks observed. In **Table 5. 2**, the mechanical removal and medicine feed treatment, in particular, became insignificant even at 10% statistical significance, while the effect of bath treatment increased in comparison with the previous model. The difference occurred because the mean and the standard deviation in the model changed for each of the binary variables due to the altered t-statistics. In order to clarify the positive impact of bath treatment, the econometric model sorted by bath and obtained the summary of the adult female lice (See Appendix A, **Table 8. 1**). When the bath treatment was implemented, even though there were less recorded observations, the mean of the adult female lice increased from 0.13 to 0.22 per fish. In other words, there were higher adult sea lice on average in the dataset. Therefore, the positive impact on female lice density can be explained by this.

Furthermore, the random effect generalized least squares (GLS) regression are implemented on the model to fix the effects by capturing the location number specific factor, which might influence the overall model. This random effect GLS regression analysis outcome can be found in Appendix A, **Table 8. 2**. After applying the random-effect regression, all treatment methods except the in-feed treatment are significant at the 1% significance level. Both cleaner fish and mechanical removal treatment methods have a negative impact on the adult female lice density however, the bath treatment has a positive impact on the lice concentration. And finally, the in-feed treatment techniques are not statistically significant in this regression model. Nevertheless, all the independent variables in each GLS regression model are jointly significant, by implementing the F-tests, which means all the models are significant. The null hypotheses are failed to be rejected when the cleaner fish and mechanical removal are taken into account.

Linear regression

Number of obs	=	40,699
F(3, 40695)	=	3483.58
Prob > F	=	0.0000
R-squared	=	0.1388
Root MSE	=	.32574

adultfemal~e	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
cleanerfisht	-.0010772	.000121	-8.90	0.000	-.0013143	-.0008401
avg_bio	.0509473	.0014585	34.93	0.000	.0480887	.053806
mobile_lice	.1266131	.0024775	51.11	0.000	.1217572	.131469
_cons	-.0409572	.0016618	-24.65	0.000	-.0442144	-.0377001

Linear regression

Number of obs	=	40,699
F(3, 40695)	=	3800.40
Prob > F	=	0.0000
R-squared	=	0.1378
Root MSE	=	.32593

adultfemalelice	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
mechanical_removal_1	-.0014726	.0008219	-1.79	0.073	-.0030836	.0001384
avg_bio	.0515901	.00146	35.34	0.000	.0487285	.0544518
mobile_lice	.1282842	.0025344	50.62	0.000	.1233167	.1332517
_cons	-.0468904	.0014224	-32.97	0.000	-.0496784	-.0441025

Linear regression

Number of obs	=	40,699
F(3, 40695)	=	3504.62
Prob > F	=	0.0000
R-squared	=	0.1378
Root MSE	=	.32593

adultfemalelice	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
medicine_feed_1	-.0015951	.0008908	-1.79	0.073	-.0033411	.0001508
avg_bio	.0513813	.001471	34.93	0.000	.0484981	.0542646
mobile_lice	.1269216	.002469	51.41	0.000	.1220823	.1317609
_cons	-.0457629	.0018549	-24.67	0.000	-.0493986	-.0421272

Linear regression

Number of obs	=	40,699
F(3, 40695)	=	3631.90
Prob > F	=	0.0000
R-squared	=	0.1406
Root MSE	=	.3254

adultfemalelice	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
medicine_bath_1	.0089908	.0007783	11.55	0.000	.0074653	.0105163
avg_bio	.0498725	.0014446	34.52	0.000	.047041	.052704
mobile_lice	.1260723	.0024828	50.78	0.000	.121206	.1309385
_cons	-.0582671	.001817	-32.07	0.000	-.0618285	-.0547057

Table 5. 1: *Regression of four treatments on adult female lice without the time and zone dummy variables.*

```
Linear regression                               Number of obs     =     40,699
                                                F(3, 40695)       =    3802.00
                                                Prob > F          =     0.0000
                                                R-squared         =     0.1378
                                                Root MSE          =     .32593

------------------------------------------------------------------------------------
                  |               Robust
  adultfemalelice |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
------------------+-----------------------------------------------------------------
mechanical_removal |  -.0053447   .0034327    -1.56   0.119     -.012073    .0013835
          avg_bio |   .0515654   .0014567    35.40   0.000     .0487103    .0544205
      mobile_lice |   .1282352   .0025476    50.33   0.000     .1232417    .1332286
            _cons |  -.0469269   .0014265   -32.90   0.000     -.049723   -.0441309
------------------------------------------------------------------------------------
Linear regression                               Number of obs     =     40,699
                                                F(3, 40695)       =    3514.56
                                                Prob > F          =     0.0000
                                                R-squared         =     0.1377
                                                Root MSE          =     .32594

------------------------------------------------------------------------------
             |               Robust
adultfemal~e |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     in_feed |  -.0017959   .0041396    -0.43   0.664    -.0099097    .0063178
     avg_bio |   .0515022   .0014747    34.92   0.000     .0486118    .0543926
 mobile_lice |   .1273195   .0024751    51.44   0.000     .1224683    .1321707
       _cons |  -.0470312    .001923   -24.46   0.000    -.0508003    -.043262
------------------------------------------------------------------------------
Linear regression                               Number of obs     =     40,699
                                                F(3, 40695)       =    3674.27
                                                Prob > F          =     0.0000
                                                R-squared         =     0.1414
                                                Root MSE          =     .32524

------------------------------------------------------------------------------
             |               Robust
adultfemal~e |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
        bath |   .0438131   .0033533    13.07   0.000     .0372405    .0503857
     avg_bio |    .049806   .0014396    34.60   0.000     .0469845    .0526276
 mobile_lice |   .1250545   .0024791    50.44   0.000     .1201955    .1299135
       _cons |  -.0601655   .0018657   -32.25   0.000    -.0638224   -.0565086
------------------------------------------------------------------------------
```

Table 5. 2: *Regression using the dummy variables for the three methods without the time and zone dummy variables*

Hypothesis II: All the year dummy variables are introduced to model to analyze if the time is a significant indicator in the aquaculture industry. The zero-one variables for each treatment method except the cleaner fish are used in this hypothesis. The base group represents the observations in 2018 with no observed lice population. In addition, excluding the cleaner fish, the base group in all three models also represents that the mechanical removal or the in-feed or the bath treatment is not implemented. The F-test implemented separately to each model to test if the regressors year12, year13, year14, year15, year16, year17, year18 are jointly statistically significant. 14.83%-14.95% of the variation in adult female lice can be explained by these econometric models. Once more there are more factors that might influence the dependent variable. All the year independent variables expect year17 have a p-value of 0.000 which denotes that they are statistically significant.

In **Table 5. 3**, the cleaner fish technique still is significant at the 1% level of significance after the year dummy variables added. Again it has a negative impact on the adult female lice dependent variable like the previous hypothesis. The F-test suggests that the year binary variables are jointly statistically significant at 1% statistical significance. (F (6, 40689) = 60.59, Prob > F = 0.0000). The null hypothesis is rejected, all the year regressors are jointly significant.

After introducing the time indicator, the mechanical removal treatment became significant even at the 1% significant level whereas it was insignificant at the 10% level of significance in the previous hypothesis **Table 5. 4**. The changes in a p-value for the mechanical removal van be explained with the multi correlation with the year dummy variables. However, it has a positive impact on adult female lice. So, the data sorted by mechanical removal and year indicated and extracted the summary of adult female lice. Even the number of observations for female lice when the treatment implemented over years were slightly less than the observations where no mechanical treatment applied, the average adult sea lice per fish are shown markedly higher (see Appendix A, **Table 8. 3**). In addition, the F-test implemented to test if the years are jointly statistically significant for mechanical removal. The results show that F (6, 40689) = 83.96, Prob > F = 0.0000, this indicates that the coefficients on the regressors year12, year13, year14, year15, year16, year17, year18 are all jointly zero and statistically significant. Thus, the null hypothesis is rejected.

```
Linear regression                               Number of obs     =     40,699
                                                F(9, 40689)       =    1274.13
                                                Prob > F          =     0.0000
                                                R-squared         =     0.1487
                                                Root MSE          =     .32389
```

adultfemal~e	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
cleanerfisht	-.0006239	.0001238	-5.04	0.000	-.0008665	-.0003812
avg_bio	.0502033	.0014507	34.61	0.000	.04736	.0530467
mobile_lice	.1367321	.0027682	49.39	0.000	.1313064	.1421579
year12	.1023965	.0069894	14.65	0.000	.088697	.1160959
year13	.0312966	.0053928	5.80	0.000	.0207265	.0418667
year14	.0761395	.0063756	11.94	0.000	.0636432	.0886359
year15	.0252819	.0047319	5.34	0.000	.0160073	.0345565
year16	.0208768	.0039244	5.32	0.000	.0131848	.0285687
year17	-.0001302	.0035005	-0.04	0.970	-.0069913	.0067309
_cons	-.0844274	.0036804	-22.94	0.000	-.0916411	-.0772137

Table 5. 3: *Regression using cleaner fish independent variable including the year dummies*

```
Linear regression                               Number of obs     =     40,699
                                                F(9, 40689)       =    1284.41
                                                Prob > F          =     0.0000
                                                R-squared         =     0.1495
                                                Root MSE          =     .32372
```

adultfemalelice	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
mechanical_removal	.0332138	.0037914	8.76	0.000	.0257826	.0406449
avg_bio	.0502291	.0014516	34.60	0.000	.0473839	.0530743
mobile_lice	.1345546	.0027732	48.52	0.000	.1291191	.13999
year12	.1220106	.0071113	17.16	0.000	.1080723	.1359489
year13	.0508403	.0056405	9.01	0.000	.0397848	.0618958
year14	.0957194	.0065324	14.65	0.000	.0829159	.108523
year15	.0440514	.0051553	8.54	0.000	.0339468	.0541559
year16	.0304735	.0039981	7.62	0.000	.0226372	.0383098
year17	.0040676	.0035267	1.15	0.249	-.0028449	.01098
_cons	-.1058284	.0037055	-28.56	0.000	-.1130913	-.0985656

Table 5. 4: *Regression using mechanical removal dummy variable including the year dummies*

For the medicinal feed treatment, **Table 5. 5** shows that the treatment methods are far away from being significant even at the 10% significance level. The outcome after implementing F test is $F(6, 40689) = 68.75$, $Prob > F = 0.0000$. The p-value is 0.0000, so the year binary variables in this model are once more jointly significant. Therefore, the null hypothesis is rejected.

Lastly in **Table 5. 6**, the bath treatment is again statistically significant at 1% statistical significance and has a positive impact on the adult female lice. The F-test (F (6, 40689) = 48.78, Prob > F = 0.0000) indicates that the year regressors are jointly significant, the null hypothesis is rejected at 1%, 5% and 10% level of significance.

Briefly, in all the models the null hypothesis indicated that the year regressors are not jointly significant and have been rejected at any significance level. In addition, as the fish biomass increases the adult female lice dependent variable will increase in all the models. If farms tend to have lice outbreaks, it will lead to higher lice concentration, as well. In addition. in the models, the year12 and year14 have the highest T-stats in comparison with the other year regressors. This proves the high average adult female lice per fish in those years. This means more treatment methods are applied to combat outbreaks in the fish farm facilities.

Linear regression			
	Number of obs	=	40,699
	F(9, 40689)	=	1280.13
	Prob > F	=	0.0000
	R-squared	=	0.1483
	Root MSE	=	.32395

adultfemal~e	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
in_feed	-.0003744	.004175	-0.09	0.929	-.0085574	.0078086
avg_bio	.0505085	.0014638	34.50	0.000	.0476393	.0533776
mobile_lice	.1375594	.0027775	49.53	0.000	.1321154	.1430035
year12	.1055668	.0069338	15.22	0.000	.0919763	.1191572
year13	.0347385	.0053245	6.52	0.000	.0243024	.0451745
year14	.0791388	.006305	12.55	0.000	.0667808	.0914968
year15	.0278246	.0046764	5.95	0.000	.0186587	.0369904
year16	.0230479	.0039133	5.89	0.000	.0153777	.0307181
year17	.0004107	.0035038	0.12	0.907	-.0064568	.0072782
_cons	-.0904106	.003586	-25.21	0.000	-.0974392	-.083382

Table 5. 5: *Regression using in-feed dummy variable including the year dummies*

Linear regression			
	Number of obs	=	40,699
	F(9, 40689)	=	1279.45
	Prob > F	=	0.0000
	R-squared	=	0.1491
	Root MSE	=	.32381

adultfemal~e	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
bath	.022254	.0035636	6.24	0.000	.0152693	.0292388
avg_bio	.0497757	.0014411	34.54	0.000	.0469511	.0526003
mobile_lice	.1348171	.0027569	48.90	0.000	.1294135	.1402207
year12	.0929922	.0069758	13.33	0.000	.0793194	.1066649
year13	.0216909	.0056189	3.86	0.000	.0106778	.0327041
year14	.0677927	.0064459	10.52	0.000	.0551585	.0804269
year15	.0178999	.0049618	3.61	0.000	.0081747	.0276252
year16	.0166232	.0040399	4.11	0.000	.0087049	.0245415
year17	-.0015087	.0035304	-0.43	0.669	-.0084284	.0054109
_cons	-.0883508	.0033435	-26.42	0.000	-.0949041	-.0817975

Table 5. 6: *Regression using bath dummy variable including the year dummies*

Hypothesis III: The zero-one variables for production zones are inserted in the econometric model. The base group represents the observations which are occurred in 2018, at the production area 13 with no observed sea lice populations. In addition, excluding the cleaner fish, the base group in all three models also represent that the mechanical removal or the in-feed or the bath treatment is not implemented. The F-test implemented separately to each model to test if the regressors prodar1, prodar2, prodar3, prodar4, prodar5, prodar6, prodar7, prodar8, prodar9, prodar10, prodar11, prodar12 are jointly statistically significant. 16.35%-16.52% of the variation in adult female lice can be explained by the model with time and production zone dummy variables. Once more there are more factors that might have an influence on the dependent variable. The production zone 3 and 4 were in red zones in 2017-2018, therefore in the analysis, it the p-value for these zones are 0.0000 in all four models which indicates that they are significant in statistical terms. All the F-tests in this analysis specify that the overall model is significant.

Linear regression			
	Number of obs	=	40,699
	F(21, 40677)	=	545.14
	Prob > F	=	0.0000
	R-squared	=	0.1639
	Root MSE	=	.32102

adultfemal~e	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
cleanerfisht	-.0006851	.0001285	-5.33	0.000	-.0009371	-.0004332
avg_bio	.0510415	.0014464	35.29	0.000	.0482066	.0538764
mobile_lice	.1262003	.002809	44.93	0.000	.1206945	.131706
year12	.0918632	.0069274	13.26	0.000	.0782853	.1054411
year13	.0244326	.0054142	4.51	0.000	.0138207	.0350446
year14	.0711485	.0062793	11.33	0.000	.0588409	.0834561
year15	.0220468	.0047036	4.69	0.000	.0128276	.031266
year16	.017988	.0038932	4.62	0.000	.0103573	.0256187
year17	-.0018378	.0034782	-0.53	0.597	-.0086551	.0049796
prodar1	-.0077076	.0255277	-0.30	0.763	-.0577425	.0423273
prodar2	.03502	.0252236	1.39	0.165	-.0144188	.0844588
prodar3	.126384	.0253034	4.99	0.000	.0767889	.1759792
prodar4	.1308344	.0254199	5.15	0.000	.0810108	.1806579
prodar5	.1167385	.0262646	4.44	0.000	.0652593	.1682177
prodar6	.0564279	.0252586	2.23	0.025	.0069204	.1059354
prodar7	.1385142	.0264228	5.24	0.000	.0867249	.1903034
prodar8	.1094013	.0256077	4.27	0.000	.0592096	.159593
prodar9	.0754844	.0257343	2.93	0.003	.0250446	.1259241
prodar10	.0641481	.026259	2.44	0.015	.0126799	.1156163
prodar11	.0037417	.0251992	0.15	0.882	-.0456493	.0531328
prodar12	.0024064	.0251577	0.10	0.924	-.0469032	.0517161
_cons	-.1626559	.0252022	-6.45	0.000	-.2120528	-.1132591

Table 5. 7: *Regression using cleaner fish independent variable including the year and production zone dummies*

In **Table 5. 7**, the cleaner fish has t-stats of -5.33 denoting that the cleaner fish negative impact on adult sea lice and significant by having a p-value of 0.000. The regressors year17, prodar1, prodar2, prodar11, and prodar12 are not significant whereas the rest of the independent variables are significant at 5% statistical significance. The F-test conducted to test if all the production zone variables are jointly equal to zero. The outcome of the test, F (12, 40677) = 157.95, Prob > F = 0.0000, points out that all the zone dummy variables are jointly significant at any level of significance. Therefore the null hypothesis is rejected.

Table 5. 8 demonstrates that mechanical removal has a positive influence on the adult female lice density. All the regressors except year17, prodar1, prodar2, prodar6, prodar11, prodar12 are significant at the 5% level of significance. However, the prodar6 independent variable is significant at the 10% significance level. The F-test result for this model is F (12, 40677) = 132.94, Prob > F = 0.0000. Once again, the production areas are jointly significant, and the null hypothesis is rejected in the mechanical removal model.

Although the in-feed treatment model suggests that the p-value of the in-feed independent variable is 0.373 which is higher than 0.10, and insignificant in **Table 5. 9**, it is lower than the previous model in the hypothesis II section. The patterns of multi correlation between in-feed and zone binary variables can be different than the earlier model, this might influence the outcome and p-value of the in_feed variable. In the model, all the variables are significant at the 5% level of significance excluding the regressors year17, prodar1, prodar2, prodar11, and prodar12. Implementing the F-test revealed that the zones in this model are jointly significant, F (12, 40677) = 151.41, Prob > F = 0.0000. Therefore the null hypothesis is rejected.

In this hypothesis, the bath treatment regressed on zone dummy variables as well. The result can be seen in **Table 5. 10**. In this model, the bath treatment has a positive impact on adult female lice and significant in statistical terms. The year13 independent variable became insignificant after introducing the area binary variables, as well as the regressor year15 became insignificant at the 5% significance level. So, leaving out year13, year15, year17, prodar1, prodar11, prodar12, rest of the independent variables are significant at the 5% statistical significance. The F-test (F (12, 40677) = 153.85, Prob > F = 0.0000) refers that the regressors prodar1, prodar2, prodar3, prodar4, prodar5, prodar6, prodar7, prodar8, prodar9, prodar10, prodar11, prodar12 are statistically jointly significant even at 1% level of significance. As a result, the null hypothesis has been rejected.

```
Linear regression                               Number of obs     =     40,699
                                                F(21, 40677)      =     551.18
                                                Prob > F          =     0.0000
                                                R-squared         =     0.1637
                                                Root MSE          =     .32106
```

adultfemalelice	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
mechanical_removal	.0135248	.0039844	3.39	0.001	.0057153	.0213344
avg_bio	.0512693	.0014484	35.40	0.000	.0484304	.0541082
mobile_lice	.1262595	.0028019	45.06	0.000	.1207676	.1317513
year12	.102452	.0070508	14.53	0.000	.0886323	.1162718
year13	.0350506	.0057389	6.11	0.000	.0238022	.0462989
year14	.0814008	.0064155	12.69	0.000	.0688262	.0939753
year15	.0316573	.0051816	6.11	0.000	.0215012	.0418134
year16	.0234754	.0040282	5.83	0.000	.0155802	.0313707
year17	.000314	.0035373	0.09	0.929	-.0066193	.0072473
prodar1	-.0146482	.0253014	-0.58	0.563	-.0642396	.0349432
prodar2	.0268863	.0250316	1.07	0.283	-.0221762	.0759487
prodar3	.1182355	.0251227	4.71	0.000	.0689943	.1674766
prodar4	.123347	.0253165	4.87	0.000	.0737261	.1729679
prodar5	.1081142	.0261368	4.14	0.000	.0568856	.1593428
prodar6	.0469176	.0250408	1.87	0.061	-.002163	.0959981
prodar7	.1285885	.0262911	4.89	0.000	.0770574	.1801197
prodar8	.1008088	.0253849	3.97	0.000	.0510538	.1505637
prodar9	.0692989	.0255367	2.71	0.007	.0192465	.1193513
prodar10	.0597612	.0260635	2.29	0.022	.0086761	.1108463
prodar11	.0008642	.0249908	0.03	0.972	-.0481183	.0498467
prodar12	-.0005952	.0249389	-0.02	0.981	-.049476	.0482857
_cons	-.1684397	.024946	-6.75	0.000	-.2173345	-.119545

Table 5. 8: *Regression using mechanical removal dummy variable including the year and production zone dummies*

In brief, the null hypothesis in hypothesis III has been rejected in all four models, this means that all the zone binary variables are jointly statistically significant in this analysis. The average biomass and mobile lice independent variables are significant and have a positive effect on the adult female lice, which appears to be reasonable. In addition, in all the model year17, prodar1, prodar11, and prodar12 regressors are not significant at any level of statistical significance.

Linear regression				Number of obs	=	40,699
				F(21, 40677)	=	548.60
				Prob > F	=	0.0000
				R-squared	=	0.1635
				Root MSE	=	.32109

adultfemal~e	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
in_feed	.0038365	.0043107	0.89	0.373	-.0046126	.0122856
avg_bio	.0515012	.0014608	35.25	0.000	.0486379	.0543645
mobile_lice	.1275098	.0027996	45.55	0.000	.1220226	.1329969
year12	.095503	.0068395	13.96	0.000	.0820974	.1089086
year13	.0282891	.005319	5.32	0.000	.0178636	.0387145
year14	.0743386	.0062016	11.99	0.000	.0621832	.086494
year15	.0245804	.0046558	5.28	0.000	.0154548	.0337059
year16	.0199859	.0038952	5.13	0.000	.0123512	.0276206
year17	-.001304	.0034838	-0.37	0.708	-.0081324	.0055243
prodar1	-.0116664	.0254571	-0.46	0.647	-.0615628	.03823
prodar2	.0314437	.0251481	1.25	0.211	-.0178472	.0807346
prodar3	.1230059	.025231	4.88	0.000	.0735525	.1724593
prodar4	.1287444	.0253524	5.08	0.000	.0790532	.1784356
prodar5	.1136084	.0262048	4.34	0.000	.0622464	.1649704
prodar6	.0511679	.0251738	2.03	0.042	.0018267	.1005091
prodar7	.1347426	.026334	5.12	0.000	.0831273	.1863579
prodar8	.1049408	.0255205	4.11	0.000	.0549201	.1549615
prodar9	.0726547	.0256836	2.83	0.005	.0223143	.1229952
prodar10	.0627667	.0262126	2.39	0.017	.0113895	.114144
prodar11	.002794	.0251424	0.11	0.912	-.0464858	.0520737
prodar12	.0010012	.0250981	0.04	0.968	-.0481916	.050194
_cons	-.1671147	.0251555	-6.64	0.000	-.2164201	-.1178094

Table 5. 9: *Regression using in-feed dummy variable including the year and production zone dummies*

Linear regression		
Number of obs	=	40,699
F(21, 40677)	=	539.72
Prob > F	=	0.0000
R-squared	=	0.1652
Root MSE	=	.32078

adultfemal~e	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
bath	.0337789	.0036918	9.15	0.000	.026543	.0410148
avg_bio	.0502519	.0014347	35.03	0.000	.0474399	.0530639
mobile_lice	.1227673	.0028088	43.71	0.000	.117262	.1282726
year12	.0756617	.0069464	10.89	0.000	.0620467	.0892768
year13	.0080067	.0057577	1.39	0.164	-.0032784	.0192919
year14	.0569165	.0063255	9.00	0.000	.0445185	.0693146
year15	.0094329	.0049657	1.90	0.057	-.0003	.0191659
year16	.0103125	.0040397	2.55	0.011	.0023946	.0182304
year17	-.0043358	.0035122	-1.23	0.217	-.0112198	.0025482
prodar1	.0159758	.0261608	0.61	0.541	-.0352999	.0672516
prodar2	.0521753	.0257995	2.02	0.043	.0016077	.102743
prodar3	.1442144	.0259062	5.57	0.000	.0934377	.1949911
prodar4	.1474938	.0260508	5.66	0.000	.0964337	.198554
prodar5	.1339887	.0268709	4.99	0.000	.0813213	.1866562
prodar6	.0721835	.0258279	2.79	0.005	.0215601	.1228068
prodar7	.1541269	.0269756	5.71	0.000	.1012542	.2069997
prodar8	.122498	.0261347	4.69	0.000	.0712735	.1737226
prodar9	.0868821	.0262677	3.31	0.001	.0353968	.1383673
prodar10	.0742538	.0267606	2.77	0.006	.0218024	.1267052
prodar11	.0156811	.025735	0.61	0.542	-.0347601	.0661222
prodar12	.0114373	.0256669	0.45	0.656	-.0388705	.0617451
_cons	-.1807329	.0257505	-7.02	0.000	-.2312044	-.1302614

Table 5. 10: *Regression using bath dummy variable including the year and production zone dummies*

6. CONCLUSION

The aquaculture industry in Norway have been grown remarkably over the years since the 1980s and created many jobs in the sector. As in every sector, the aquaculture industries are also facing many challenges. However, the ectoparasites called salmon louse is one of the main pain points for this industry, since the lice are attached to Atlantic salmon and affect the quality of the fish health that causes severe injuries or even death. Therefore, the application of treatment methods is essential to sustain steady growth. In this thesis, four treatment methods that are used for reducing the lice density have been analyzed, which are cleaner fish, mechanical removal, in-feed, and bath treatments. Three hypotheses are conducted to investigate their impact on the adult female lice and tested on the STATA 16.0. In this concluding part, the main findings of the regressions, and limitations are summarized.

In the first hypothesis, the effects of each treatment method on adult female lice and their significance are measured, using different methods. In the first method, the original variables for the mechanical removal, in-feed, and bath were held. The cleaner fish, mechanical removal, and in-feed have a negative influence on adult female lice, whereas bath treatment have a positive impact. All four treatment methods are statistically significant at the 10% level of significance. So, the null hypotheses except the bath treatment are failed to be rejected. In the second method, the dummy variables for the mechanical removal, in-feed, and bath introduced. The base group for these treatment applications represents that there is no treatment applied in the farm and no outbreaks observed. The bath treatment remains significant even at the 1% significance level and to have a positive influence on adult female lice. However, the mechanical removal and in-feed zero-one variables became insignificant in both of the models. Lastly, in hypothesis I, the random effects GLS regressions are implemented after fixing the facts. This regression outcome pointed out that both cleaner fish and mechanical removal have an impact on adult female lice negatively, whereas the bath treatment maintains a positive effect. All the treatment methods excluding in-feed treatment are significant at any level of statistical significance. The null hypothesis is failed to be rejected for cleaner fish and mechanical removal.

The second hypothesis is carried out to investigate whether the years affect adult sea lice density. The F-test for analyzing the joint significance of all the year dummy variables is applied to each of the treatment methods. In all four econometric models, the F-test is tested one by one. All the treatment methods indicated that the year independent variables jointly significant at the 1% level of significance. Therefore, the null hypothesis is rejected. Furthermore, all the binary variables denoting the years, besides year17, are statistically significant and positively effects the dependent variable. The year12 and year14 regressors, when the highest lice epidemic was observed, have the highest impact on the model.

In the last hypothesis, the dependence of adult female lice on the production zone is evaluated for every treatment technique. Once more the F-test performed to demonstrate the joint significance of the binary variables of the production areas. The outcome of all the regressions illustrated that the production area dummy variables are jointly statistically significant at the 1% significance level. The null hypothesis has been rejected in hypothesis III.

In all the models, average biomass, and mobile lice, which refers to whether the farm experienced any outbreaks, had a positive impact on the dependent variable, and both of these independent variables were statistically significant even at the 1% significance level.

One limitation of these models is the absence of data for adult female lice, fish biomass, and the applied treatment methods. 11,205 observations are excluded in the model which denotes 21.6% of overall data. In addition, there is no information regarding the timing effect. So, it is not possible to know when the treatment methods were performed, and when the adult female lice were counted. Moreover, the sensitivity reports denote that the lice began to have high resistance to the active substances that are used in bath and in-feed treatment over the years (Rueness et al., 2019). The sensitivity report might explain the insignificance of in-feed treatment and the positive impact of bath treatment chemical usage. The limitations on the source might impact on explaining the positive impact and insignificance of some of the treatment methods. Conducting the binary variable for cleaner fish was not feasible, because the population of the cleaner fish does not stay the same. After the treatment occurred, the cleaner fish are taken out of the cages. Therefore, the binary variable for the cleaner fish had not been taken into consideration.

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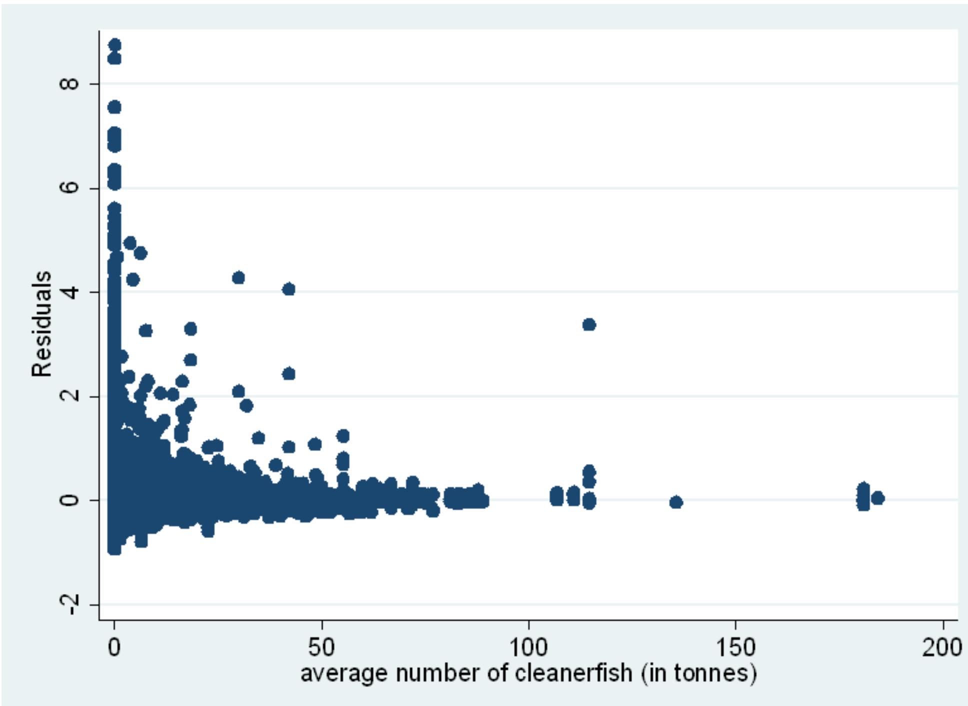
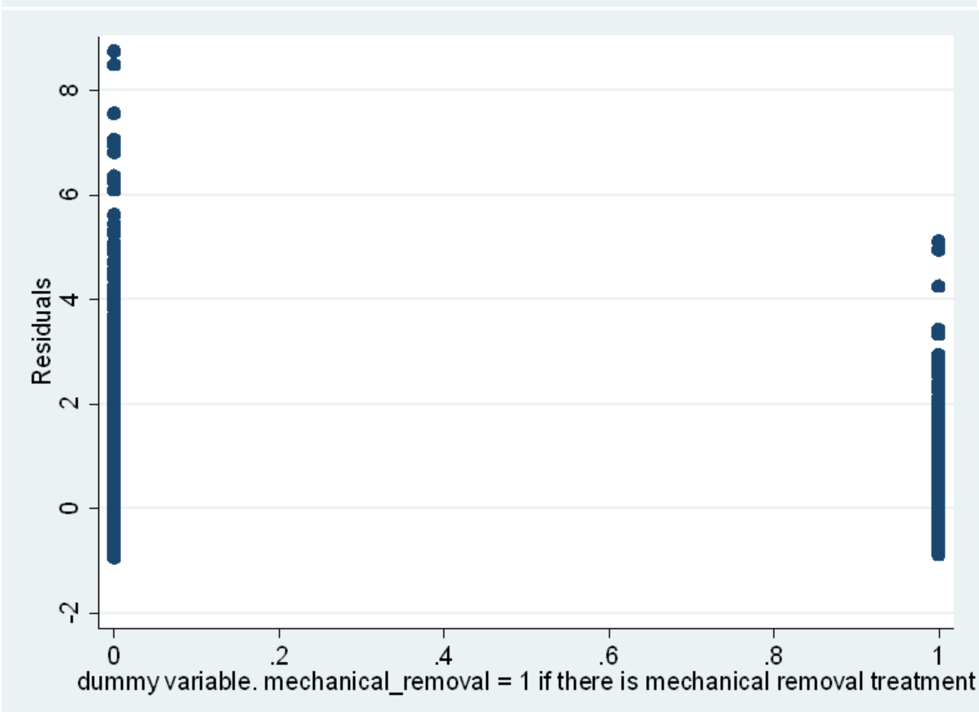
APPENDICES

Appendix A





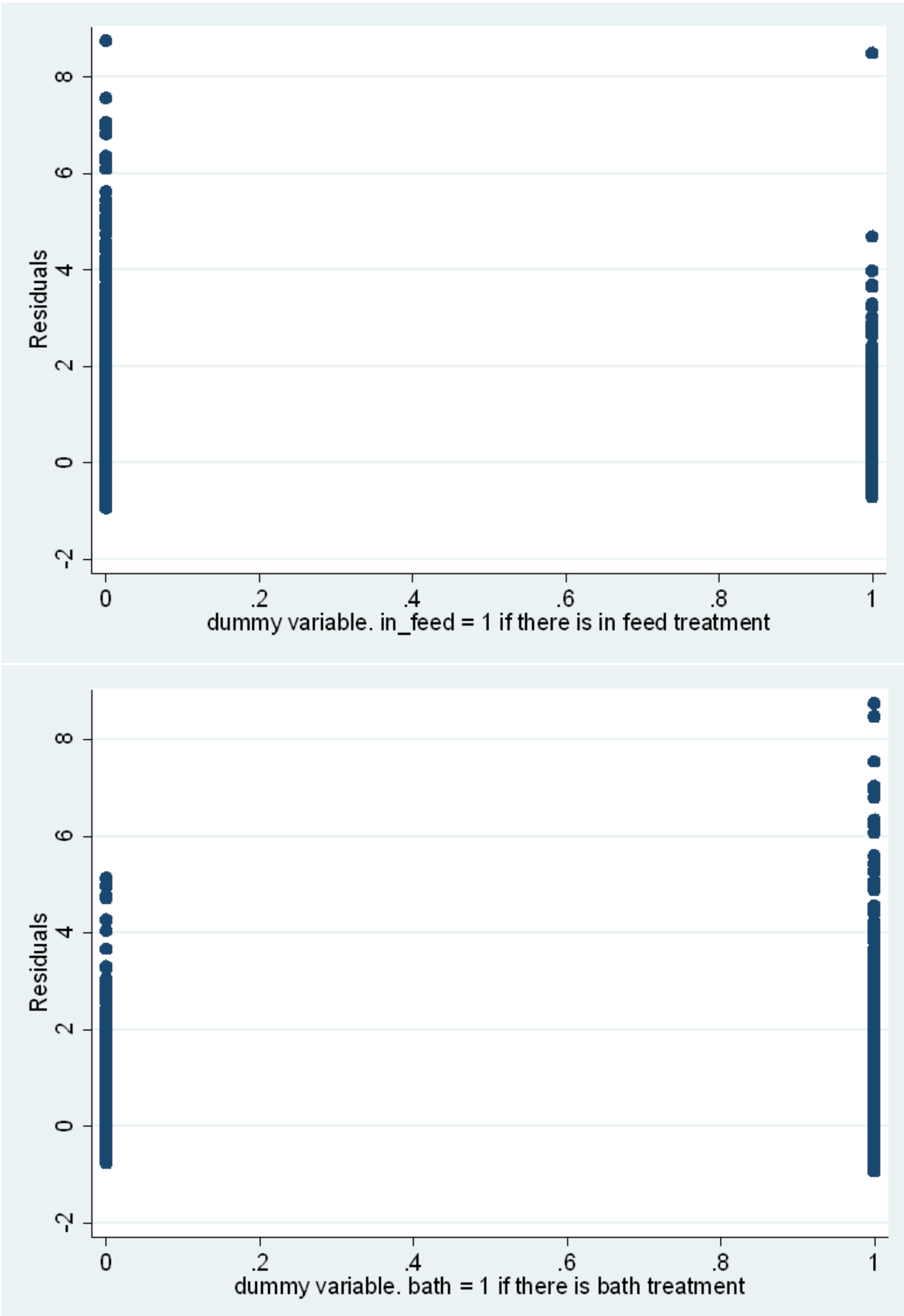


Figure 8. 1: *Residuals vs. predictor plot graphs for each treatment*

```
-> bath = 0
```

Variable	Obs	Mean	Std. Dev.	Min	Max
adultfemal~e	23,370	.1372192	.2507422	0	5.4

```
-> bath = 1
```

Variable	Obs	Mean	Std. Dev.	Min	Max
adultfemal~e	17,329	.2269481	.4471386	0	9.467999

Table 8. 1: *The summary of adult female lice after sorting the data by bath*

```
Random-effects GLS regression                   Number of obs     =     40,699
Group variable: location_n                      Number of groups  =      1,005

R-sq:                                           Obs per group:
     within  = 0.1324                                         min =          1
     between = 0.2062                                         avg =       40.5
     overall = 0.1381                                         max =         78

                                                Wald chi2(3)      =    6288.14
corr(u_i, X)   = 0 (assumed)                    Prob > chi2       =     0.0000
```

adultfemal~e	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
cleanerfisht	-.0008043	.000162	-4.96	0.000	-.0011218	-.0004868
avg_bio	.0551153	.00092	59.91	0.000	.0533122	.0569184
mobile_lice	.1059334	.0043413	24.40	0.000	.0974246	.1144423
_cons	-.0322152	.0054665	-5.89	0.000	-.0429294	-.0215009
sigma_u	.12006022					
sigma_e	.31273658					
rho	.12844976	(fraction of variance due to u_i)				

```
Random-effects GLS regression                   Number of obs     =     40,699
Group variable: location_n                      Number of groups  =      1,005

R-sq:                                           Obs per group:
     within  = 0.1326                                         min =          1
     between = 0.2012                                         avg =       40.5
     overall = 0.1368                                         max =         78

                                                Wald chi2(3)      =    6288.12
corr(u_i, X)   = 0 (assumed)                    Prob > chi2       =     0.0000

------------------------------------------------------------------------------------
     adultfemalelice |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
---------------------+--------------------------------------------------------------
mechanical_removal   |  -.0204353   .0040837    -5.00   0.000    -.0284392   -.0124315
             avg_bio |   .0556855   .0009159    60.80   0.000     .0538903    .0574806
         mobile_lice |   .1092244   .0043695    25.00   0.000     .1006604    .1177885
               _cons |  -.0346236   .0054156    -6.39   0.000     -.045238   -.0240093
---------------------+--------------------------------------------------------------
             sigma_u |  .12067049
             sigma_e |  .31270149
                 rho |  .12961459   (fraction of variance due to u_i)
------------------------------------------------------------------------------------
```

```
Random-effects GLS regression                   Number of obs     =     40,699
Group variable: location_n                      Number of groups  =      1,005

R-sq:                                           Obs per group:
     within  = 0.1320                                         min =          1
     between = 0.2033                                         avg =       40.5
     overall = 0.1371                                         max =         78

                                                Wald chi2(3)      =    6259.37
corr(u_i, X)   = 0 (assumed)                    Prob > chi2       =     0.0000

------------------------------------------------------------------------------
adultfemal~e |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     in_feed |  -.0014171   .0049522    -0.29   0.775    -.0111232     .008289
     avg_bio |   .0555296   .0009259    59.97   0.000     .0537148    .0573444
 mobile_lice |   .1065658   .0043474    24.51   0.000     .0980451    .1150865
       _cons |  -.0366026   .0055439    -6.60   0.000    -.0474685   -.0257367
-------------+----------------------------------------------------------------
     sigma_u |  .12064371
     sigma_e |  .31281734
         rho |  .12948098   (fraction of variance due to u_i)
------------------------------------------------------------------------------
```

```
Random-effects GLS regression                   Number of obs     =     40,699
Group variable: location_n                      Number of groups  =      1,005

R-sq:                                           Obs per group:
     within  = 0.1359                                         min =          1
     between = 0.2107                                         avg =       40.5
     overall = 0.1407                                         max =         78

                                                Wald chi2(3)      =    6476.81
corr(u_i, X)   = 0 (assumed)                    Prob > chi2       =     0.0000
```

adultfemal~e	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
bath	.0481939	.0035134	13.72	0.000	.0413077	.0550801
avg_bio	.0537379	.0009233	58.20	0.000	.0519282	.0555476
mobile_lice	.1037248	.0043354	23.92	0.000	.0952276	.1122221
_cons	-.0516548	.0054759	-9.43	0.000	-.0623874	-.0409221
sigma_u	.11981396					
sigma_e	.31210908					
rho	.12843976	(fraction of variance due to u_i)				

Table 8. 2: *Random-effects GLS regressions outcome for each treatment model.*

-> year = 2012, mechanical_removal = 0

Variable	Obs	Mean	Std. Dev.	Min	Max
adultfemal~e	5,066	.2367711	.4986007	0	8.8

-> year = 2012, mechanical_removal = 1

Variable	Obs	Mean	Std. Dev.	Min	Max
adultfemal~e	289	.2444637	.4588	0	3.63

-> year = 2013, mechanical_removal = 0

Variable	Obs	Mean	Std. Dev.	Min	Max
adultfemal~e	5,139	.1585944	.362583	0	7.875

-> year = 2013, mechanical_removal = 1

Variable	Obs	Mean	Std. Dev.	Min	Max
adultfemal~e	350	.2126186	.4078595	0	3.68

-> year = 2014, mechanical_removal = 0

Variable	Obs	Mean	Std. Dev.	Min	Max
adultfemal~e	5,481	.2160215	.4742054	0	9.467999

-> year = 2014, mechanical_removal = 1

Variable	Obs	Mean	Std. Dev.	Min	Max
adultfemal~e	322	.2641548	.4926597	0	4.5275

-> year = 2015, mechanical_removal = 0

Variable	Obs	Mean	Std. Dev.	Min	Max
adultfemal~e	5,462	.1599567	.3134412	0	5.75

-> year = 2015, mechanical_removal = 1

Variable	Obs	Mean	Std. Dev.	Min	Max
adultfemal~e	388	.2771942	.4811026	0	5.4

```
-> year = 2016, mechanical_removal = 0

    Variable |        Obs        Mean    Std. Dev.       Min        Max
-------------+---------------------------------------------------------
adultfemal~e |      3,933    .1356253    .2474147          0   4.766667

-------------------------------------------------------------------------
-> year = 2016, mechanical_removal = 1

    Variable |        Obs        Mean    Std. Dev.       Min        Max
-------------+---------------------------------------------------------
adultfemal~e |      1,969     .217987    .2712612          0       5.31

-------------------------------------------------------------------------
-> year = 2017, mechanical_removal = 0

    Variable |        Obs        Mean    Std. Dev.       Min        Max
-------------+---------------------------------------------------------
adultfemal~e |      3,302    .1176557    .2192959          0     4.8825

-------------------------------------------------------------------------
-> year = 2017, mechanical_removal = 1

    Variable |        Obs        Mean    Std. Dev.       Min        Max
-------------+---------------------------------------------------------
adultfemal~e |      2,702    .1836325    .2117796          0   3.286667

-------------------------------------------------------------------------
-> year = 2018, mechanical_removal = 0

    Variable |        Obs        Mean    Std. Dev.       Min        Max
-------------+---------------------------------------------------------
adultfemal~e |      2,779    .0975285    .2166048          0       7.27

-------------------------------------------------------------------------
-> year = 2018, mechanical_removal = 1

    Variable |        Obs        Mean    Std. Dev.       Min        Max
-------------+---------------------------------------------------------
adultfemal~e |      3,517    .1738376    .2074428          0   2.936667
```

Table 8. 3: *The summary of adult female lice after sorting the data by mechanical treatment and year*

Appendix B

STATA Codes

. drop if adultfemalelice ==.

. drop if biomass_kg==0

```
. drop if productionarea_n ==.

. drop if cleanerfisht == .

. gen avg_bio = biomass_kg / fishinventory

. gen mobile_lice = adultfemalelice > 0

. gen mechanical_removal = mechanical_removal_1 > 0

. gen in_feed = medicine_feed_1 > 0

. gen bath = medicine_bath_1 > 0

. reg adultfemalelice cleanerfisht avg_biomass mobile_lice, vce(robust)

. reg adultfemalelice medical_removal avg_biomass mobile_lice, vce(robust)

. reg adultfemalelice in_feed avg_biomass mobile_lice, vce(robust)

. reg adultfemalelice bath avg_biomass mobile_lice, vce(robust)

. gen year12 = year==2012

. gen year13 = year==2013

. gen year14 = year==2014

. gen year15 = year==2015

. gen year16 = year==2016

. gen year17 = year==2017

. reg adultfemalelice cleanerfisht avg_biomass mobile_lice year13 year14 year15 year16 year17
year18, vce(robust)

. reg adultfemalelice mechanical_removal avg_biomass mobile_lice year13 year14 year15
year16 year17 year18, vce(robust)

. reg adultfemalelice in_feed avg_biomass mobile_lice year13 year14 year15 year16 year17
year18, vce(robust)
```

. reg adultfemalelice bath avg_biomass mobile_lice year13 year14 year15 year16 year17 year18, vce(robust)

. gen prodar1 = productionarea_n==1

. gen prodar2 = productionarea_n==2

. gen prodar3 = productionarea_n==3

. gen prodar4 = productionarea_n==4

. gen prodar5 = productionarea_n==5

. gen prodar6 = productionarea_n==6

. gen prodar7 = productionarea_n==7

. gen prodar8 = productionarea_n==8

. gen prodar9 = productionarea_n==9

. gen prodar10 = productionarea_n==10

. gen prodar11 = productionarea_n==11

. gen prodar12 = productionarea_n==12

. reg adultfemalelice cleanerfisht avg_biomass mobile_lice year13 year14 year15 year16 year17 year18 prodar1 prodar2 prodar3 prodar4 prodar5 prodar6 prodar7 prodar8 prodar9 prodar10 prodar11 prodar12, vce(robust)

. reg adultfemalelice mechanical_removal avg_biomass mobile_lice year13 year14 year15 year16 year17 year18 prodar1 prodar2 prodar3 prodar4 prodar5 prodar6 prodar7 prodar8 prodar9 prodar10 prodar11 prodar12, vce(robust)

. reg adultfemalelice in_feed avg_biomass mobile_lice year13 year14 year15 year16 year17 year18 prodar1 prodar2 prodar3 prodar4 prodar5 prodar6 prodar7 prodar8 prodar9 prodar10 prodar11 prodar12, vce(robust)

```
. reg adultfemalelice bath avg_biomass mobile_lice year13 year14 year15 year16 year17 year18
prodar1 prodar2 prodar3 prodar4 prodar5 prodar6 prodar7 prodar8 prodar9 prodar10 prodar11
prodar12, vce(robust)
```