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The Environmental Effectiveness of Sea Lice Regulation: Compliance and Consequences for Farmed and Wild Salmon

Mari Lie Larsen, The Fridtjof Nansen Institute, Fridtjof Nansens vei 17, 1366 Lysaker, Norway, mllarsen@fni.no

Irja Vormedal, The Fridtjof Nansen Institute, Fridtjof Nansens vei 17, 1366 Lysaker, Norway, ivormedal@fni.no

Corresponding author: Mari Lie Larsen, + 47 99716657, mllarsen@fni.no,

The Fridtjof Nansen Institute, Fridtjof Nansens vei 17, 1366 Lysaker, Norway

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Highlights

- This study evaluates the environmental effectiveness of sea-lice thresholds in salmon aquaculture by examining whether industry compliance lessens sea-lice infestation pressures on surrounding wild populations.
- Strict lice thresholds have reduced the average number of lice per fish within sea farms, but more frequent de-lousing action has led to declining fish welfare and higher mortality rates.
- Successful compliance with sea-lice thresholds has no observable, positive effect on the sea-lice infestation pressure on wild salmon
- The environmental effectiveness of stricter sea-lice thresholds is limited, and should be accompanied by targeted, complementary measures

Abstract

Wild Atlantic salmon populations are declining. Since the 1970s, the proportion returning to Norwegian rivers has been almost halved, while Norwegian sea farming has undergone massive industrialization and expansion. As the proliferation of sea lice is an important part of the explanation for the decline in wild salmon, Norway has enacted increasingly stricter regulatory thresholds for the average number of lice per farmed fish at production sites. This study shows that setting stricter thresholds has led to declining lice-levels within sea farms, but that more frequent de-lousing measures to ensure compliance leads to farmed-salmon welfare problems and higher mortality rates. Compliance with stricter thresholds has not lessened the sea-lice infestation pressure on surrounding, wild salmonid populations. The environmental effectiveness of such regulation is thus limited. This raises the important question of whether a regulatory regime focused on minimizing the average number of sea lice per farmed fish may do more harm than good, unless accompanied by a broader set of regulatory instruments targeting other variables that affect sea-lice infestations in the wild salmon habitat.

Keywords

Atlantic salmon, salmon farming, sea lice, regulation, environmental effectiveness,

1. Introduction

The wild Atlantic salmon, also known as the "King of Fish," is famed for its epic, oceanic migrations, moving thousands of kilometers from its natal river through the oceans of the Northern Hemisphere and back. A thriving wild salmon stock is considered an indicator of ecological and environmental health—and its near-iconic status among fishermen and recreational anglers, its rich cultural history and importance for local employment, has made it a centerpiece for ecotourism.

However, in recent decades, Atlantic Salmon populations in Europe and North America have declined (ICES, 2019). That led to the establishment of inter-governmental efforts to protect the survival of this unique species through the North Atlantic Salmon Conservation Organization (NASCO), whose members include Canada, Denmark (Faroe Islands/Greenland) the EU, Norway, the Russian Federation, and the USA. As approximately one third of all Atlantic salmon spawns within Norwegian waters, Norway has a clear responsibility for safeguarding the global stock (Helgesen, 2016; Hindar et al., 2011; Parliamentary proposal, 2006). Since the 1970s, the total capture of salmon has dropped by 75%, and the proportion returning to rivers has been almost halved (Forseth et al., 2019). In parallel, salmon farming has mushroomed, from being a small-scale, supplementary activity for local farmers in the 1960s and 70s, to a full-fledged, export-oriented global industry. Between 1994 and 2017, Norwegian production volumes grew from 200 thousand to more than 1300 tons, corresponding to more than 400 million farmed individuals at nearly 800 sites along the entire coast (Directorate of Fisheries, 2019). Today, stocks of farmed salmon are 720 times greater than stocks of wild Atlantic salmon (Forseth et al., 2019).

The proliferation of sea lice—a parasite that thrives in dense, fish-farming sites—has been shown to be an important part of the explanation for the decline in wild salmon that return to Norwegian rivers (Forseth et al., 2017; Heuch et al., 2005; Kristoffersen et al., 2018; Svåsand et al., 2017). When salmon smolt migrate from their natal rivers during spring, passing a "belt" of salmon farms on their way towards the open sea, they often become heavily infested with sea lice. If such an infestation reaches between 0.04 and 0.15 mature lice per gram smolt weight, it may cause high stress levels and reduce the smolt's swimming ability, heightening the risk of mortality at sea (Nolan et al., 1999; Tveiten et al., 2010; Wagner et al., 2004, 2003)

To resolve the challenge of sea lice-induced mortality for wild Atlantic salmon, Norway has implemented increasingly stricter regulations since 2013. This article investigates

Norwegian fish-farmers' compliance with new regulations that set maximum thresholds for average number of sea lice per farmed fish at production sites. It evaluates the consequences for farmed salmon, and discusses the environmental effectiveness of such regulation: to what degree do they lessen the sea-lice infestation pressure and mortality risks for surrounding wild Atlantic salmon? Previous research has studied the effects of diseases and lice-reducing measures on farmed salmon, as well as spill-over effects from increased sea-lice proliferation on wild salmon returns (Costello, 2009a, 2006; Krkošek et al., 2005; Serra-Llinares et al., 2016, 2014; Torrissen et al., 2013). However, few studies have examined the link between industry compliance with sea-lice thresholds and risks for wild populations, and whether the regulation has been environmentally effective. These are important issues. More knowledge about the link between regulatory compliance and wild salmon mortality risks is needed to evaluate goal attainment. Low goal attainment, combined with negative economic and health effects on farmed salmon, may indicate that regulations are poorly designed and targeted, causing unnecessary harm.

After a brief discussion of the sea-lice challenge, and an account of Norway's new regulatory regime, we present a statistical analysis of fish-farmer compliance with the sea-lice thresholds set for production sites. Our analysis focuses on three key production areas which cover much of the fjords and coastlines in two west-coast counties of Norway, Vestland and Møre & Romsdal. These represent pertinent cases for study due to the high density of fish-farming sites, and the government's evaluation of their impact on surrounding wild populations under the "Traffic light system" as "unacceptable". We then examine available research and data on wild salmon, to see whether successful compliance correlates with reduced lice-infestation pressure and thus mortality risks. In conclusion, we discuss the environmental effectiveness of regulating sea-lice levels in fish farms, and whether other types of regulatory instruments might improve goal attainment.

2. The Sea-Lice Challenge

The term "sea lice" refers to a group of tiny, parasitic copepods (small crustaceans), the most biologically and economically damaging parasites to the salmonid farming industry worldwide (Costello, 2009b, 2006). In the Northern Hemisphere, the most harmful sea louse is the *Lepeophteheirus salmonis*, or salmon louse (Costello, 2006; Torrissen et al., 2013). Like most parasites, the salmon louse is totally dependent on its host, feeding off the skin, mucus, and blood. It is a natural and integral part of the ecosystem, and has existed for millions of years.

However, the expansion of salmon farming has led to a marked expansion in sea-lice hosts, resulting in more favorable conditions for parasite growth and transmission, in turn creating problems for the industry and wild salmonids alike. The wild Atlantic salmon is anadromous, migrating from freshwater rivers to the open sea and back during its lifecycle. Returning salmons are naturally, and nearly always infested with lice, even in areas with few salmon farms (Copley et al., 2005; Torrissen et al., 2013). Since the parasite cannot survive in freshwater, the lice will detach from the host when it returns to its river. However, the amplification of hosts due to industry growth and increased stocking density has heightened the risks of sea lice attaching to young, post-smolt salmonids on their seaward migration route towards an offshore habitat. The effect on the salmon stock is assumed to be linked to this migration phase.

A mature female louse may produce several hundred eggs, depending on the sea temperature. The eggs can hatch to larvae, which will at some point detach and spread to the surrounding commons via water currents, where they may attach to migrating wild individuals, or to farmed individuals in nearby production sites (Samsing et al., 2017). The amount of infective larvae produced in an area will thus depend on the number of hosts (both wild and farmed), and number of mature female lice per host. Larval production is also affected by water temperature (Boxaspen and Næss, 2000). This is mainly a problem for the young, migrating post-smolt, which can tolerate maximum 0.04–0.15 lice per gram of fish weight before stress levels are heightened, swimming abilities are reduced, and disturbances are created in their water/salt balance (Grimnes and Jakobsen, 1996; Nolan et al., 1999; Thorstad and Finstad, 2018; Tveiten et al., 2010; Wagner et al., 2008, 2004, 2003). Wagner et al. (2008) have found that infections of 0.75 lice per gram fish, or 11 lice for a 15 g smolt, may prove fatal if all the lice develop into the pre-adult and adult stages. This is consistent with the finding of field studies on salmon lice infections on salmon post-smolts in the Norwegian Sea (Holst et al., 2003).

To prevent the spread of sea lice and sea-lice larvae from farming sites to wild salmon smolts, governments set mandatory and maximum thresholds for the amount of mature or motile lice per farmed fish at production sites (Luthman et al., 2019).[1] For Canada, Chile, and Scotland the threshold has been set at an average of 3 motile lice per fish (Luthman et al., 2019), while the Faroe Islands have set a threshold of 1.5 mature female lice per fish (Gislason, 2018). Norway has the strictest standard: maximum 0.2 mature lice per fish during

[1] *Motile* refers to the pre-mature stage when the louse is able to move around on its host; a *mature* louse is in its adult stage when the female can produce eggs

the smolt spring migration period, and 0.5 otherwise (Luthman et al., 2019; Ministry of Trade, Industry and Fisheries, 2012).

3. Norwegian Regulations

The salmon louse has represented a serious problem for the Norwegian salmon farming industry since the 1970s (Brandal and Egidius, 1977). By 2010, it had become widely acknowledged that the proliferation of sea lice was beginning to threaten the health and survival of wild salmonid populations as well. The government and industry faced public criticism for having prioritized growth over the protection of wild salmon; and in 2012, the National Audit Office warned that the environmental problems had become so severe that substantial new regulations were needed (Hersoug et al., 2019; Office of the Auditor General, 2012; Vormedal and Skjærseth, 2019). The same year, the government concluded that the industry had serious problems with sea lice but also with diseases and escapement (Ministry of Trade, Industry and Fisheries, 2013).

From 2013, the Norwegian government begun to implement increasingly stricter sea-lice regulations. Under Regulation no. 1140, all farms were first required to keep lice levels below an average of 0.5 adult female lice per fish. This was further tightened in 2017, to require levels below 0.2 in the most "vulnerable" weeks (16–22), which affect the migration period for wild smolt. All permit-holders were obliged to count and report the average number of lice per fish throughout the year at all production sites,[2] and to slaughter in accordance with breaches of the new lice limits. Further, the government introduced a new category of "green permits" in 2013, setting permissible sea-lice levels averaging between 0.25 and 0.1[3]. In 2015, applications for "capacity increases" (permission to increase the maximum allowed biomass (MAB) limit for existing permits) were also made conditional on keeping lice-levels below 0.2 at the relevant farming sites. Finally, in 2017 the government implemented a new regulatory regime, the "Traffic Light System" (TLS). The TLS divides Norway into 13 production areas (PAs), in which the sea-lice infestation pressure on wild salmon is evaluated. To give advice on lice-induced mortality risks in each PA, the Ministry of Trade, Industry and Fisheries requested the Institute of Marine Research (HI), the Veterinary Institute (VI) and the Norwegian

[2] Fish farmers count the lice every week, and only every second week if the water temperature is below 4º C. Both mature and motile lice are reported.

[3] Although the stricter lice limits had been announced when the green permits scheme was announced, evaluation of the permits later showed that the permits did not in fact constrain stricter lice limits. (See Hersoug and Robertsen, 2020)

Institute of Natural Research (NINA) to establish a *steering group* (Boxaspen et al., 2017), which in turn appointed an *expert group* composed of scientists, to conduct annual risk assessments pertaining to the impact of sea lice on wild salmon in each PA. They also prepare recommendations to the steering group. Risk assessments are based on a combination of i) hydrodynamic dispersion models, which predict the spread of lice larvae from production sites based on reported lice levels, sea temperature, and water currents; and ii) data from the national surveillance program for salmon lice on wild salmon (NALO), which are used to verify the models (Nilsen et al., 2018). The steering group evaluates the recommendations of the expert group, and provides advice to the Ministry every other year based on the recommendations derived from the two preceding years. The appraisals of these two groups provide the main basis for the government's decision to set a green, yellow or red "traffic light" for each PA (Ministry of Trade, Industry and Fisheries, 2017, 2020). Companies with permits within a PA deemed to have an "acceptable" impact on wild salmon (green light) may buy a set percentage increase in production volumes at a fixed price from the government (2% in 2018 and 1% in 2020). They may also participate in auctions where allowances to increase production volumes by up to 6% are sold, after added volumes bought at a fixed price have been deducted. Companies with permits within a PA deemed to have a "moderate" impact (yellow light) are allowed to maintain current production volumes, whereas companies with permits within a PA deemed to have an "unacceptable" impact will be punished with a requirement to reduce production volumes by 6%. However, the regime also includes an exception: if companies with permits within yellow or red areas can demonstrate sea-lice levels below 0.1, they may also buy increases in production volumes of up to 6% at a fixed price.

4. Material and Methods

Our analysis is based on statistical data from the Norwegian Food Safety Authority, the Directorate of Fisheries and the Ministry of Trade, Industry and Fisheries. Salmon farming companies are required to report production-related data—including biomass, infections/diseases, lice counts, as well as medicinal and other treatments—to the authorities on a regular basis. Our panel dataset covers data from all salmon-producing sites in Norway between January 2012 and January 2020: altogether some 850 fish-farming sites with 445 million individual salmonids (Directorate of Fisheries 2019). As a more stringent reporting system was implemented in 2012, pre-2012 data are not comparable. All the data used are openly accessible to the public, except for the farming sites' monthly inventory data, to which we have been granted access from the Directorate of Fisheries. Our analyses draw largely on data from production during weeks 16–21, which will affect the period of the year when the wild salmon smolt migrate from their natal rivers and pass by fish-farming sites on their way to the open sea (weeks 21–26 in northern parts of Norway).

We provide nationwide data, which give an overall impression of the average lice-level development, but focus specifically on production areas (PAs) 3, 4 and 5, which basically cover the fjords and coastline of the two counties Vestland and Møre & Romsdal (Fig. 3). These PAs are relevant for examining the environmental effectiveness of lice thresholds, as all three were deemed to have "unacceptable" impact on wild salmonids within the new Traffic Light System (TLS) in 2017 and/or 2020. When the government first "turned on" the traffic lights in 2017, both PAs 3 and PA 4 received an unacceptable impact and red-light status. However, in 2020, despite the steering group's conclusion that there was still a high risk[4] for wild salmon populations in both areas, the government decided to attribute PA 3 a moderate impact and yellow-light status, while PA 4 kept its unacceptable impact and red-light status. PA 5, on the other hand, was deemed to have a moderate risk[5] in 2017 and a high risk in 2020, which corresponded to the government's attribution a "moderate impact" and yellow light in 2017, and an "unacceptable" impact and red light in 2020.[6]

We wanted to compare data from the red PAs with data from a green PA deemed to have an "acceptable" impact on wild salmonids in both periods. To optimize such a comparison, we selected a green area with framework conditions as similar as possible to the three red PAs. We considered PA 7 to be the most appropriate candidate. It had received a green light from the government in both periods (Ministry of Trade, Industry and Fisheries, 2017, 2020), although the steering group concluded that there was a moderate mortality risk for wild salmonids there in 2017 (Boxaspen et al, 2017). PA 7 is also similar in size to the other PAs and it is the geographically closest PA that has wild-fish surveillance data starting from 2015 (see the Appendix for more details on the PA selection process). For comparison across the areas, we generally use percentage presentation of the data, as there are variations in number of

[4] "High risk": the likelihood that more than 30% of the wild salmon smolt might not survive due to salmon-lice infestation

[5] "Moderate risk": the likelihood that between 10% and 30% of the wild salmon smolt might not survive due to salmon-lice infestation

[6] We assume that the apparent discrepancy between the government's traffic lights and the expert and steering groups' assessment of mortality risk has political causes. More research is needed to investigate the politics behind traffic-light setting.

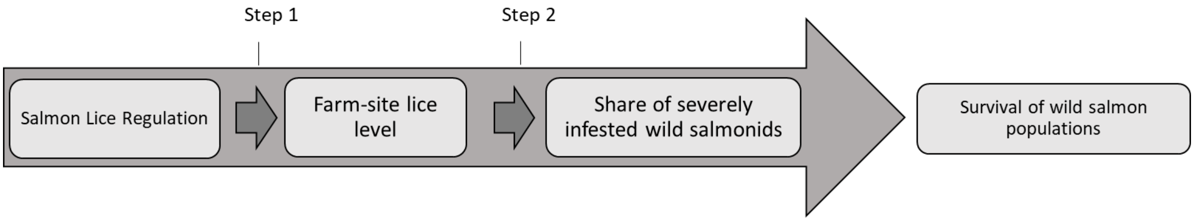
farm sites and stock of fish among the different areas examined. We have accounted for this in our evaluation of the results.

In analyzing compliance, we compare data from before 2017, when the sea-lice threshold was on average 0.5 mature female lice per fish, with data after 2017, when the threshold was lowered to 0.2. In addition, we evaluate the distribution of events of overruns (non-compliance) and the corresponding frequency of treatments. See Table 1 in the Appendix for an overview of the statistical processing of the data.

Our examination of the infestation pressure on the wild salmonids reviews relevant scientific data and reports from monitoring programs, scientific consultation or advisory groups appointed by the government. We use published data from the salmon lice surveillance program for wild salmon (NALO), conducted by Norway's Institute of Marine Research on behalf of the Norwegian Food Safety Authority (see Appendix I and II in Institute of Marine Research, 2019a; also 2019b, 2018, 2017, 2016)). The aim of the program is to obtain robust data on salmon lice infestation on wild salmonids in all production areas. NALO field surveys are conducted from late April till early August; quality-assured data are published annually. NALO employs various methods to monitor lice-infestation pressure. We base our study on the methods most frequently used in most of the PAs along the entire coast: data from fish traps/nets and trawling. There is low uncertainty given a representative coverage in time and space (Nilsen et al., 2018). An overview of the number of wild salmonids tested and method used can be found in the Appendix. Our analysis is based on reports on location (fjord system), testing method and the week number of testing, number of fish tested, and share of fish tested with more than 0.1 lice per gram weight (i.e. severely infested). These figures have been taken directly from the NALO reports. We then categorize the data on the basis of which production area encloses the test site, and the year of the test, to calculate the share of all tested fish with more than 0.1 lice per gram within each PA for each year. Despite some variation in the number of tested fish across the different PAs, and between the different years, we have opted to use these aggregated data as representative samples for the different areas. Data from weeks 19 to 26 are relevant for salmon smolt migration for the areas investigated, and are thus the weeks used in our analysis. In some fjord systems, cages filled with smolt have been set out at specific locations to monitor the lice infestation. Although smolt-cage data could provide important information about infection pressure, we do not include this dataset, as that method is not used in all the PAs, and the reporting scheme is not comparable to the other datasets (Bjørn et al, 2011). According to the Institute of Marine Research, post-2017 data have not been quality assured and have therefore not yet been published (Norwegian Marine Data Centre, 2015). Further, we compare and discuss the annual conclusions of the expert group (Nilsen et al, 2017; 2018; Vollset et al, 2019)) against our own analysis of NALO surveillance data. As the regulatory system is relatively new, historical data are limited, and that might bias our statistical analysis. However, it is important to examine trends for the time-series available, to get a preliminary idea of the effects and environmental effectiveness of the regulatory regime. Such an analysis can be used as a source of feedback and a tool for improving performance and systematizing knowledge. On the other hand, given the complexity of the ecological system, the regulatory system involves considerable uncertainty and requires constant re-evaluation. Looking for patterns in such a complex system is challenging. Notwithstanding limitations related to the data and methods used, we believe our effort to advance knowledge on the relationship between regulatory compliance and wild fish mortality risks is valuable.

Figure 1 sums up our research design. In step 1, we investigate the effect of salmon lice regulation on lice levels at production sites, examining fish-farmers' compliance with regulations, as well as unintended and negative effects of such compliance. In step 2, we evaluate the environmental effectiveness of sea-lice regulation by considering to what extent reducing the average number of lice per farmed fish at production sites appears to lessen the infestation pressure on surrounding wild salmon populations. After all, that is the fundamental environmental objective of Norwegian regulation of lice-levels at production sites, and the sole indicator used to evaluate the environmental impact of fish farming in the Traffic Light System. To help answer this overarching research query, we investigate a range of more specific questions: Does successful compliance with stricter sea lice thresholds at production sites correlate with a lower share of severely infested wild salmonids? Does a higher number of farm sea lice in a production area (PA) correlate with a higher share of severely infested wild salmonids? And finally, does a higher number of lice in a PA due to non-compliance correlate with a higher share of severely infested wild salmonids? Analyzing the broader environmental repercussions of salmon farming is beyond the scope of this article. For more comprehensive analyses of environmental impacts, see for instance Glover et al., 2017; Olaussen, 2018; Samuelsen et al., 2015; Grefsrud et al., 2019.

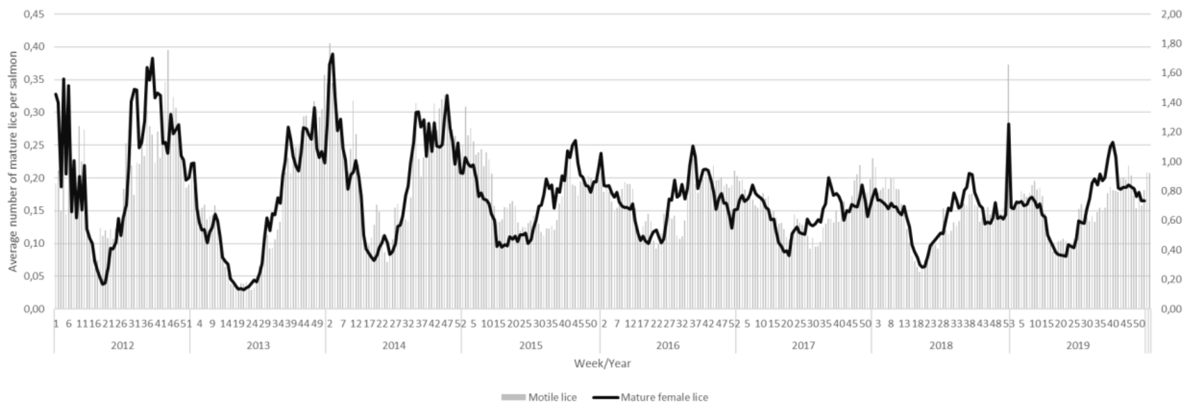
Figure 1. Research design



5. Industry Compliance, Consequences for Farmed Salmon

Figure 2 shows average lice levels at all Norwegian production sites, 2012–2019. Fluctuations in the course of the year are due to seasonal variations; however, we can observe an overall decline in the average lice level in recent years (Fig. 2).

Figure 2 Average level of mature (left axis) and motile (right axis) lice, nationwide



Notes to Fig. 2: The black line shows average reported mature female lice levels; the light-gray bars are reported motile lice in Norway. Based on data from Lusedata, January 2020. http://lusedata.no/statistikk/excel/

However, a positive nationwide trend may mask large local variations. The lice problem has been particularly severe along the west coast of southern Norway (PA 3-5) (Fig. 3), where the waters are warmer and there are many fish-farming sites. The production areas located there—PA 3, 4, and 5—are the only ones deemed to have "unacceptable" impacts on surrounding wild populations.

Figure 3: Overview of production areas. Modified from Overton et al., 2019

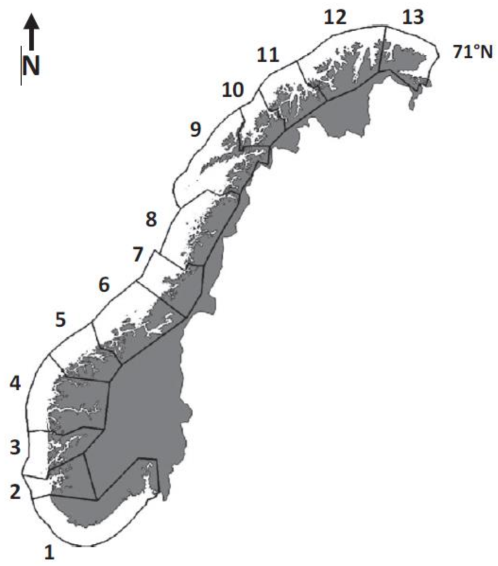
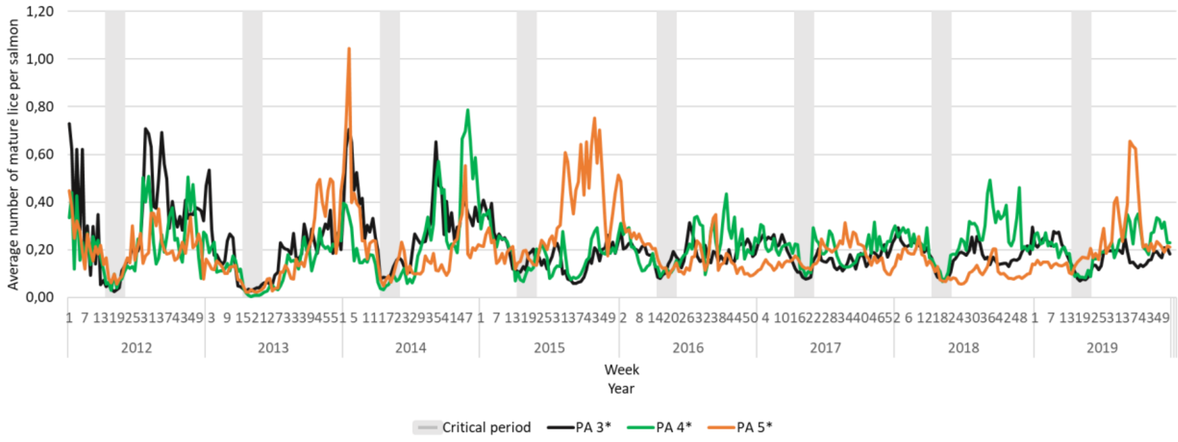


Figure 4 indicates the development of average lice levels over time in these areas. From 2015, the average level has been significantly improved for PA 3, with no observable outbreaks. By contrast, PAs 4 and 5 have experienced considerable fluctuations in recent years, especially in 2018 and 2019. In the analysis, we examine the period of the year when lice infestation is most critical for wild salmon, and the lice-level threshold is tightened to an average of 0.2 adult female lice per fish: weeks 16 to 21 (marked in gray columns). On average, fish-farming sites within all the PAs investigated have stayed within or at the 0.2 threshold, except for PA 4, which was slightly above in 2017 (see Appendix, Table 2, for details).

Figure 4 Development of average lice levels in PA 3 (black), P 4(green) and PA 5 (orange)

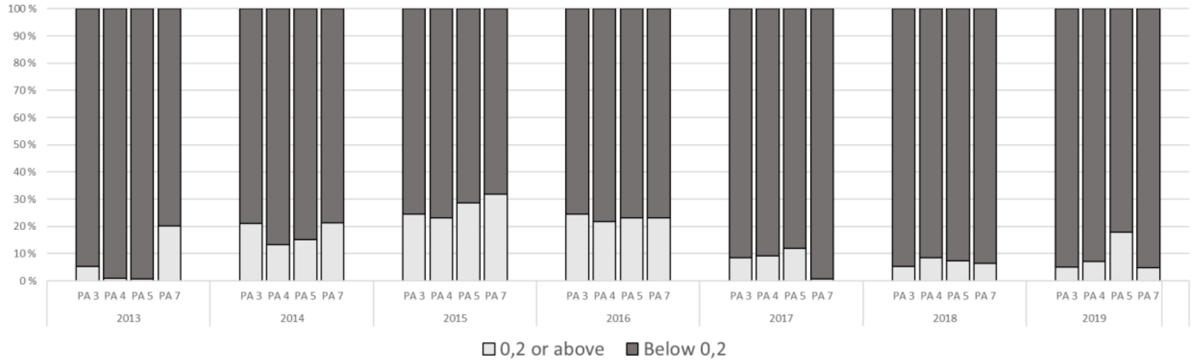


Notes to Fig. 4: Data available for average lice levels are based on county borders, as the division into PAs did not come until 2017. PA 3* refers to sites in the county of Hordaland, which is representative of PA 3; PA 4*, to sites in Sogn & Fjordane, representative of PA 4. PA 5* refers to sites in Møre & Romsdal, where there are slightly more sites than in PA 5, which might affect this graph. Source: Based on data from Lusedata, January 2020. http://lusedata.no/statistikk/excel/

We now turn to the lice situation at the level of the individual production site. Figure 5 shows the portion of production sites that maintained levels below 0.2 in PAs 3, 4 and 5, from 2013 to 2019. For reference, we include data from PA 7, further north, which had “acceptable impact” status on wild salmon mortality (“green light”) in both 2017 and 2020.

The stricter threshold was not implemented until 2017; as evident from Figure 5, in all the PAs studied, more sites stayed below 0.2 after this. For 2018 and 2019, 95% of the production sites in PA 3 managed to comply with the 0.2 threshold; in PA 4, 92% complied in 2018 and 93% in 2019. PA 5 was less successful, especially in 2019, when only about 82% of the sites managed to comply. In PA 7, the share of compliance was similar to PA 3: 94% in 2018 and 95% in 2019.

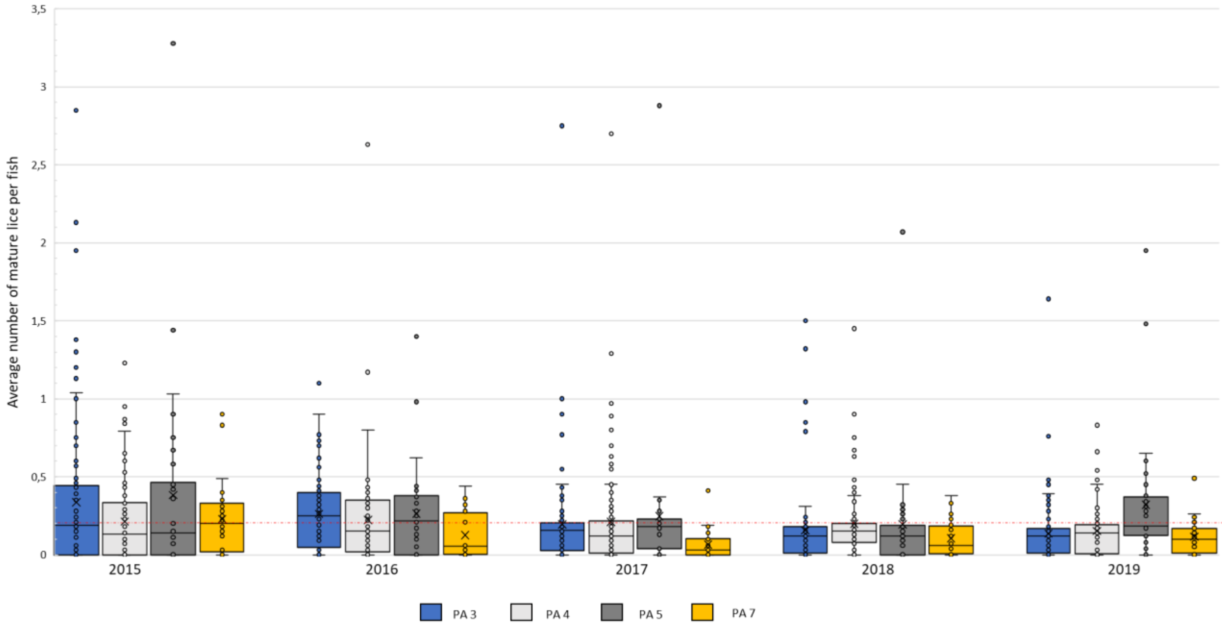
Figure 5. Share of production sites in PAs 3, 4, 5, and 7 complying with 0.2 threshold, 2014–2019



Notes, Fig. 5: From 2013 to 2016, fish-farmers were required to implement coordinated de-lousing treatments during spring, to reduce the infestation pressure for wild salmon; however, the regulatory threshold was kept steady at 0.5 throughout the year. Source: Based on data from Barentswatch, January 2020. https://www.barentswatch.no/nedlasting/fishhealth/lice

Figure 6 shows the overall distribution of reported average lice levels (maximum reported level from each site, weeks 16–21) from all sites in each PA. The upper quartile (the top of the box column), was significantly lowered from 2016 to 2017 for all PAs, which indicates less spread in the data. The median has also been reduced. Distribution has remained basically stable for PAs 3, 4, and 7, but PA 5 experienced an increase in lice levels in 2019. Our examination of the amount and frequency of overruns (below) shows that the same production sites tend to have repeated overruns.

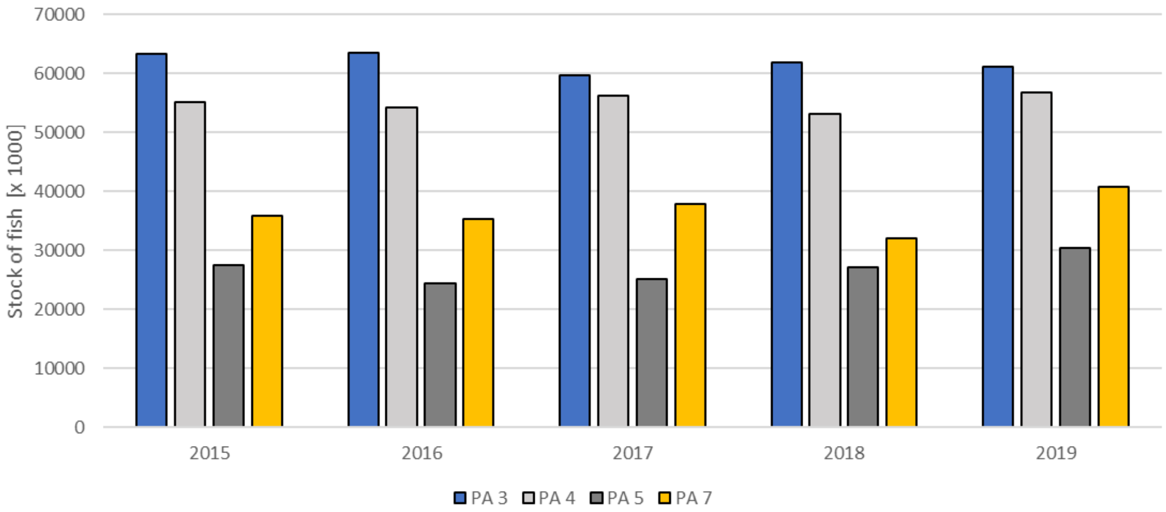
Figure 6. Distribution of reported lice levels within each PA, 2015–2019



Source: See Fig. 5

Although the average lice level per fish within each area has decreased after implementation of the stricter threshold in 2017, the total number of lice also depends on variations in the number of fish within the same area. With a constant average per fish, the total amount of lice will increase apace with increasing numbers of salmon at production sites. However, investigation of the biomass in each of the PAs shows that the fish stocks have remained basically constant during the corresponding period, with only a slight increase for PA 5 and PA 7 in 2019 (Fig. 7). Furthermore, biomass in PAs 3 and 4 is significantly higher than in PAs 5 and 7.

Figure 7. Stock of fish in PAs 3, 4, 5 and 7, 2015 to 2019

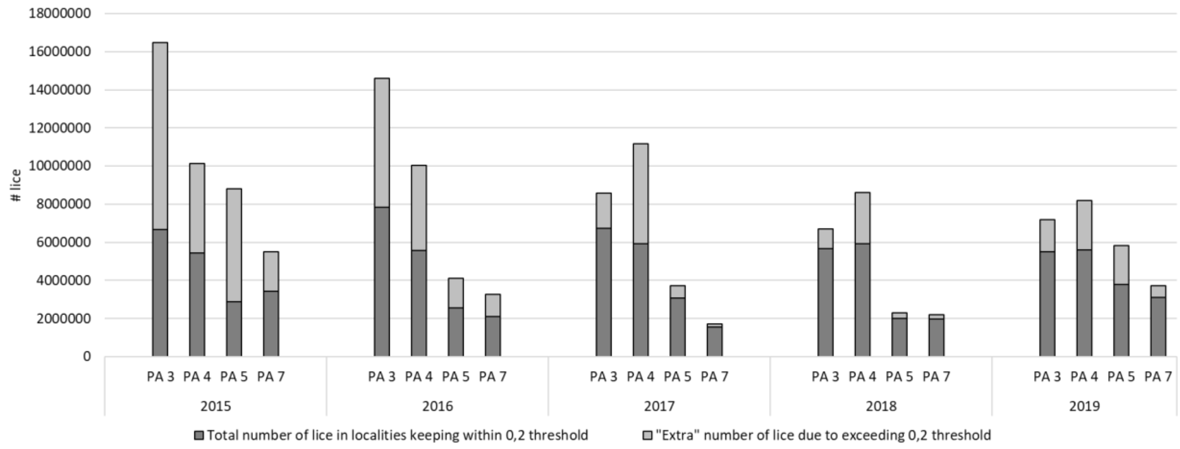


Source: See Fig. 5

From the biomass and lice reports we calculate the actual number of lice in each PA (Fig. 8). The bars are divided into two parts; the sum represents the total number of lice. The dark-colored part of the bars shows the total amount of lice for all sites that stayed below 0.2; the light-colored part indicates the additional amount of lice due to sites exceeding the 0.2 threshold.[7] In PA 3 we note a gradual decline in total number of lice from 2015 to 2018, with a slight increase in 2019. The light-gray part of the column decreased significantly from 2016 to 2017—less lice, due to compliance with 0.2 threshold. In PA 4, the total lice level was highest in 2017, apparently unaffected by the new regulation. For PA 5, total levels were lower than in PAs 3 and 4 until 2019. In 2018, PA 5 had over 70% less lice than PAs 3 and 4, and about the same amount as in PA 7. Levels in both PA 5 and PA 7 rose significantly in 2019, due to greater numbers of fish (Fig. 7), as well as a higher average lice level per fish for both areas (Fig. 6).

[7]For sites exceeding 0.2 we calculated a hypothetical number of lice as if the sites had been kept below 0.2 (i.e. exchanged the actual mean level of lice per fish for the site with a mean level of 0.19 lice per fish), and used this figure to indicate the extra amount of lice due to overruns.

Figure 8. Number of lice per PA, 2015–2019

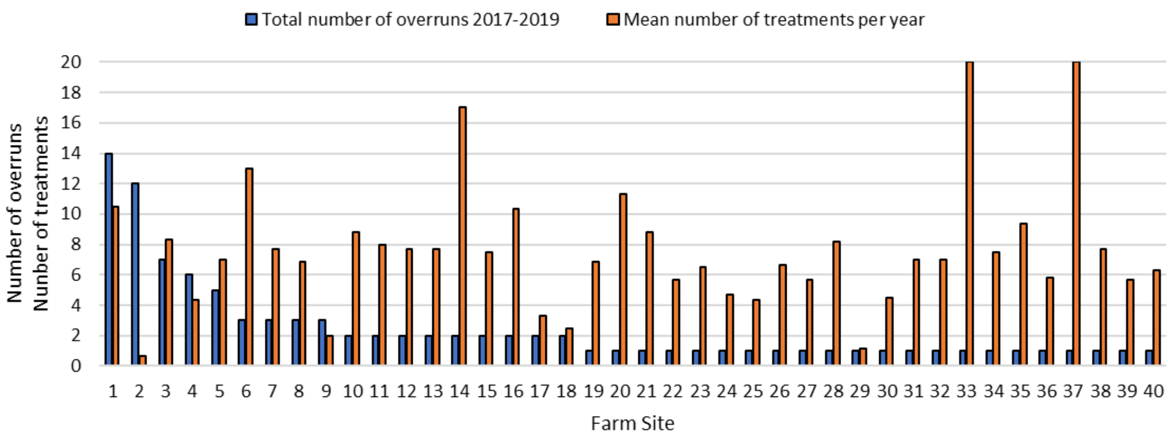


Source: See Fig. 5

Is failure to comply with stricter thresholds a matter of resource use—or it is perhaps due to less-controllable natural circumstances? We now turn to individual production sites in the area with the highest number of sites and biomass, namely PA 3, and examine the relationship between non-compliance and the number of de-lousing treatments (Fig. 9).

Figure 9 provides an overview of all production sites that failed to comply with the 0.2 threshold in the critical weeks in the years 2017–2019 (blue column), and the average annual number of mitigation measures 2017–2019 (orange column). Sites 1 and 2 stand out, with 14 and 12 incidents of non-compliance, respectively. However, while site no. 1 conducted 11 treatments on average per year, site no. 2 conducted only one (or fewer) treatments, as seen from the orange column. There are other sites that have fewer incidents of non-compliance but that conducted many treatments (e.g. sites 33 and 37), whereas some conducted few treatments and had few incidents of non-compliance (e.g. sites 9, 17, 29). It is possible that sea lice simply thrive better at some sites, despite frequent de-lousing actions by farmers (see also Institute of Marine Research, 2020). Overall, our data show that fish-farmers have largely succeeded in implementing the stricter thresholds.

Figure 9. Relationship between non-compliance and number of de-lousing treatments

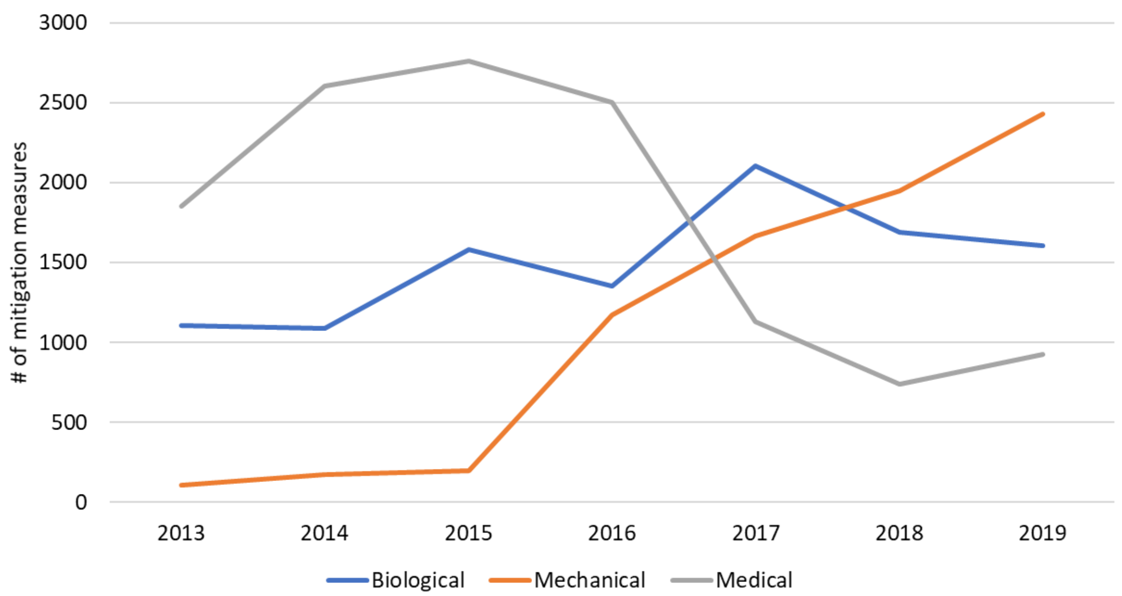


Source: Based on data from Barentswatch, January 2020.
https://www.barentswatch.no/nedlasting/fishhealth/treatments

Various methods are used to control and reduce salmon lice levels at production sites. Traditionally, medical measures, such as pharmaceutical treatments, predominated. However, as the lice increasingly developed resistance, the effect vanished and the problem escalated, forcing the industry to develop new, non-medical methods, which we categorize as "biological" or "mechanical." One biological solution involves the use of "cleaner-fish": lice-eating species like lumpfish and wrasse. In Norway in 2018, a total of 41.6 million cleaner-fish (mostly lumpfish) were farmed, in addition to some 20 million wild-caught wrasse, and were put into the net pens to clean the salmon. However, significant health and welfare problems arose (Hjeltnes et al., 2019), with more than 40% of the cleaner-fish dying (Grefsrud et al., 2019). The Food Safety Authority has now focused on the welfare of cleaner-fish, and stricter regulations are expected (Norwegian Food Safety Authority, 2019).

As to pharmaceutical measures, there was a period dominated by hydrogen peroxide treatment, but the industry experienced events with high salmon mortality, and the lice appeared to develop resistance. New mechanical solutions are now being applied, using various flushing techniques, fresh-water treatment, slightly-heated water and optic laser-guns. There is discussion of the effects of these new approaches on fish welfare. Thermal delousing, where the salmon are exposed to heated water (approx. 28–35°C) (Gismervik et al, 2018; Overton et al., 2019), has been shown to cause serious stress to the fish (Overton et al., 2019), and the Norwegian Food Safety Authority has now recommended phasing out the method over two years, unless new data prove that it can be used in a welfare-justifiable manner. Sudden exposure to warm water causes immediate behavioral responses indicative of nociception or pain in Atlantic salmon: after five minutes in 28° water, four out of five fish showed signs of imminent death (Nilsson et al., 2019). Moreover, a study of the effect of even higher water temperatures (34–38° C) found that exposing salmon to such water temperatures is a direct welfare risk, entailing tissue injuries and thermal pain and aversion, with acute stress responses (Gismervik et al., 2019). From Figure 10, showing the rise in the use of mechanical and biological (cleaner-fish) delousing methods, and the decline in medical treatments, 2013–2019, we see that mechanical treatment is increasingly dominant. Over the same period, the data also indicate a strong positive correlation (0.93) between the intensity of lice-reduction operations at production sites and farmed salmon mortality (Figure 11).[8] The number of mitigating events (Y-axis) includes the use of cleaner-fish, but mechanical treatments (including hydrogen peroxide) dominate. The correlation with mortality rate could be due to increased use of these non-biological technologies. However, a strong correlation is not the same as causation: there might be several other factors affecting the two variables.

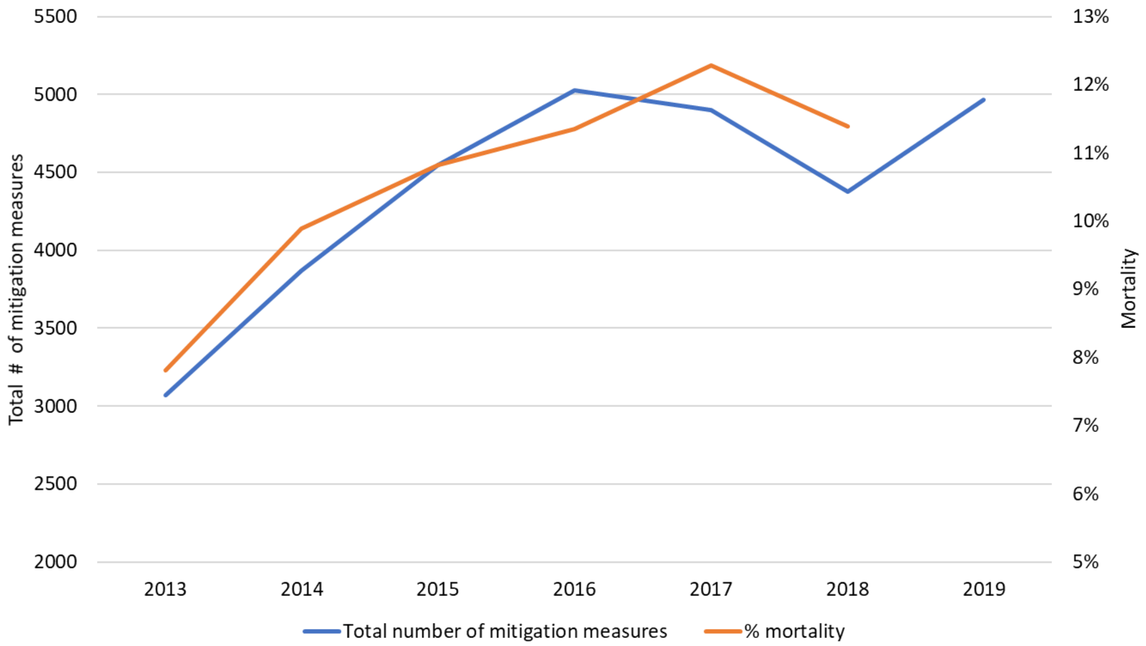
Figure 10. Number of de-lousing treatments



Source: See Fig. 9

[8] We have summarized the number of treatments performed both at entire sites and parts of the site. As the reporting schemes do not give details on which net pens are treated at the specific site, frequency may be affected by farmers tending to treat only parts of the sites.

Figure 11. Number of de-lousing actions and farmed fish mortality



Source: Based on data from Barentswatch, January 2020, https://www.barentswatch.no/nedlasting/fishhealth/treatments; Directorate of Fisheries, January 2020. https://www.fiskeridir.no/Akvakultur/Tall-og-analyse/Biomassestatistikk/Biomassestatistikk-etter-fylke

Although the stricter lice regulation has had an overall positive effect on lice levels in the PAs, the unintended effects on the welfare and survival of farmed fish are extensive. Here, we do not consider the economic consequences of a surge in de-lousing actions, which has been discussed at length elsewhere (see Abolofia et al., 2017; Brakstad et al., 2019; Costello, 2009b; Iversen et al., 2020, 2017).

6. Sea-Lice-Induced Mortality Risks for Wild Salmon Stocks

The Norwegian government has appointed several independent scientific groups relevant to the protection of wild Atlantic salmon, including the salmon lice surveillance program for wild salmon (NALO), which was established to monitor and document sea lice on wild salmon smolt when these migrate out to sea. Data from NALO are incorporated into the Traffic Light System's annual expert group assessment of lice-induced mortality risks for wild salmonid populations. As seen in Table 1, the expert group categorizes the risk level in each PA as either high, moderate or low for wild salmon populations. According to the expert group, NALO data involve less uncertainty than the dispersion models—a reason for conducting our own analysis of NALO data.

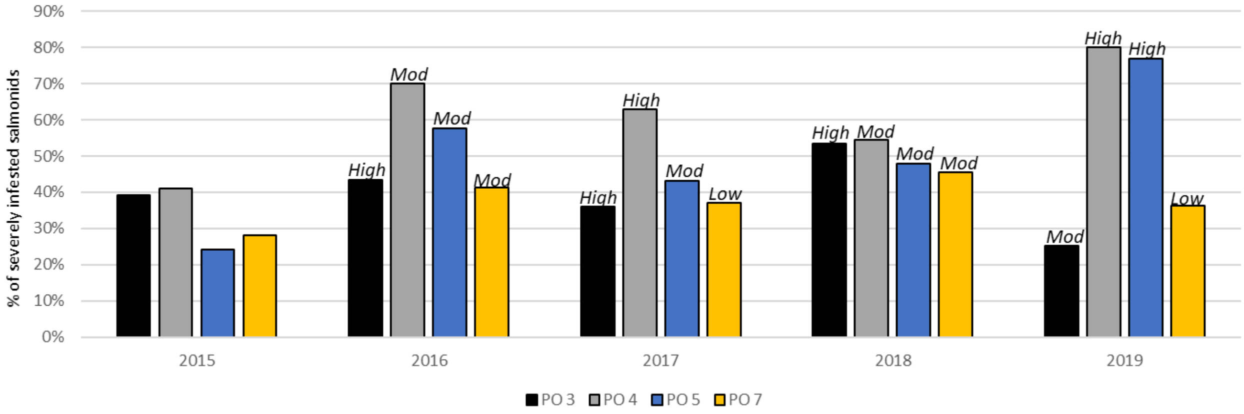
Table 1. Summary of conclusions of the expert group for PA 3,4,5 and 7

	2016	2017	2018	2019
PA 3	High	High	High	Mod
PA 4	Mod	High	Mod	High
PA 5	Mod	Mod	Mod	High
PA 7	Mod	Low	Mod	Low

Turning to the data from NALO, we account for the share of tested wild salmonids that had more than 0.1 lice per gram weight. As smolt experience reduced swimming ability, heightened stress levels and disturbances in their water and salt balances when infested with between 0.04-0.15 lice per gram of weight, experts have set 0.1 as a threshold indicating severe mortality risk. A high share of severely infested wild salmonids in a PA is thus related to high lice infestation pressure.

Figure 12 shows the total share of severely infested wild salmonids in PAs 3, 4, 5 and 7 during the smolt migration period (see Table 3 in the Appendix for an overview). In PA 3 there was a surge in 2018, with more than 50% of the salmonids severely infested. Then, in 2019, the share dropped to about 25%—the lowest level in five years. For PA 4, the share first declined between 2016 and 2018, but rose significantly in 2019, with about 80% of the tested fish severely infested. PA 5 shows a similar development: close to 80% of the tested fish were severely impacted in 2019. For PA 7, the share was about the same in 2016 and 2017 as observed in PA 3. In 2018, PA 7 had the lowest share of severely infested wild salmonids among the PAs studied here, as did PA 3 in 2019.

Figure 12. Share of wild salmonids infested with > 0.1 lice per gram, PAs 3, 4, 5, and 7



Note: Data labels indicate the expert group's conclusion for each PA

The data labels (high, moderate, low) specify the risk level set by the expert group for each PA. By converting these levels into numbers—1 equaling low risk, 2 moderate risk, and 3 high risk—we can do a simple correlation between the share of severely infested salmonids and the risk level. Compared to the expert group's conclusions, analysis of NALO data shows a strong positive correlation for PAs 3 (0.80), 5 (0.91), and 7 (0.91), seen in isolation. For PA 4, on the other hand, there is weaker correlation between the two variables (0.49). For example, from 2016 to 2017, NALO data indicate a reduction in infestation pressure, while the expert group conclusion indicates a rise of risk, from moderate to high.

An overall assessment across the areas shows only a moderate correlation (0.48) between the expert group conclusions and NALO monitoring data. In 2017, PA 3 had about 35% severely infested wild salmonids and was deemed to have a "high" risk of lice-induced mortality. However, the same levels of salmonid were infested in PA 7, where the expert group concluded that there was a "low" risk of mortality. This difference is also evident in 2019: PA 3 was deemed to have a moderate risk, with about 25% of the wild salmonid severely infested, and PA 7 to have low risk, with about 35% of the wild salmonid severely infested. Overall, it seems that a lower level of infested wild salmonids is required in PA 3 compared to the other areas to obtain the same risk score.[9] Several factors are incorporated in the risk evaluations of

[9] While the reason for this is unknown, it could be linked to the fact that more intense monitoring of wild salmonids has been conducted in PA 3 over several years, that this area has been viewed as a particularly

the expert group; however, as noted, the expert group considers NALO's monitoring data to have the least uncertainty compared to the models used.

7. The Environmental Effectiveness of Sea Lice Regulation

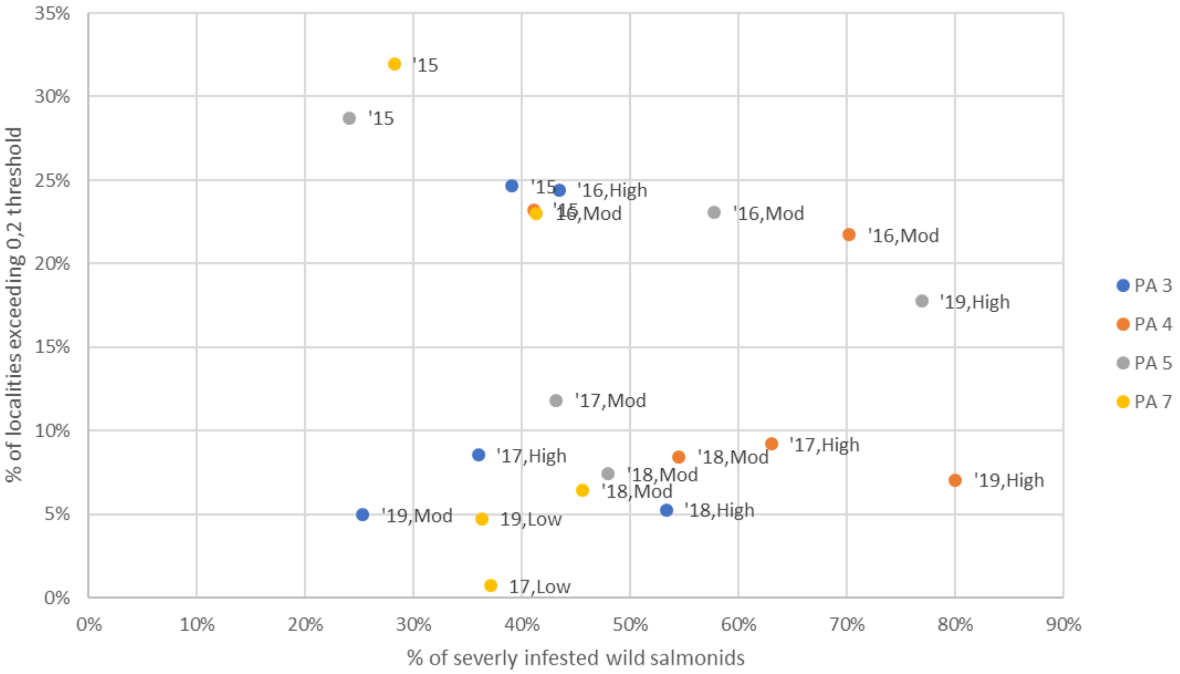
Have lower sea-lice levels in farmed-salmon production sites lessened the mortality risks for wild salmon populations? Although the number of sea lice per farmed fish has decreased as a result of successful compliance with the set thresholds, the problem of lice-induced mortality risks for wild salmonids seems far from resolved. High proportions are still severely infested with sea lice. We now turn to the relationships between variables related to compliance and variables related to the infestation pressure on wild salmonids.

We begin with the relationship between the share of production sites exceeding the threshold average of 0.2 adult female lice per fish per year and the share of severely infested wild salmonids in the corresponding PA per year (Fig. 13). If a higher share of the farm sites within the PAs exceeds this threshold, does the infestation pressure on the wild salmonids rise? Across all the PAs, the two variables show a weak negative correlation (−0.14). In 2015 and 2016, when the limit was still 0.5, a higher share of the sites in all PAs exceeded 0.2, as could be expected. However, this was not reflected in a higher share of severely infested wild salmonids. For instance, in 2015 in PA 5, close to 30% of the sites had lice levels higher than 0.2, but less than 25% of the wild salmonids were severely infested—the lowest share among the PAs studied here. In comparison, in PA 4, only 7% of the sites exceeded the threshold in 2019, but as much as 80% of the wild salmonids were severely infested. A comparison across the different PAs can be misleading, as geographically dependent variables may influence the results. However, examining each PA separately, we still find no significant, positive correlation between the two variables for all the years investigated (See Table 4 in the Appendix for an overview of correlation coefficients).

Further, is a higher share of sites successfully kept within the threshold consonant with a lower mortality risk level set by the expert group? We find a weak positive correlation (0.26) between these variables across all areas for the period evaluated by the expert group (2016-2019). Examining each PA in isolation gives a stronger correlation for all areas, except PA 4.

problematic area for a substantial time, and a higher number of wild salmonids are tested here compared to the other areas. This may in turn affect the level of uncertainty.

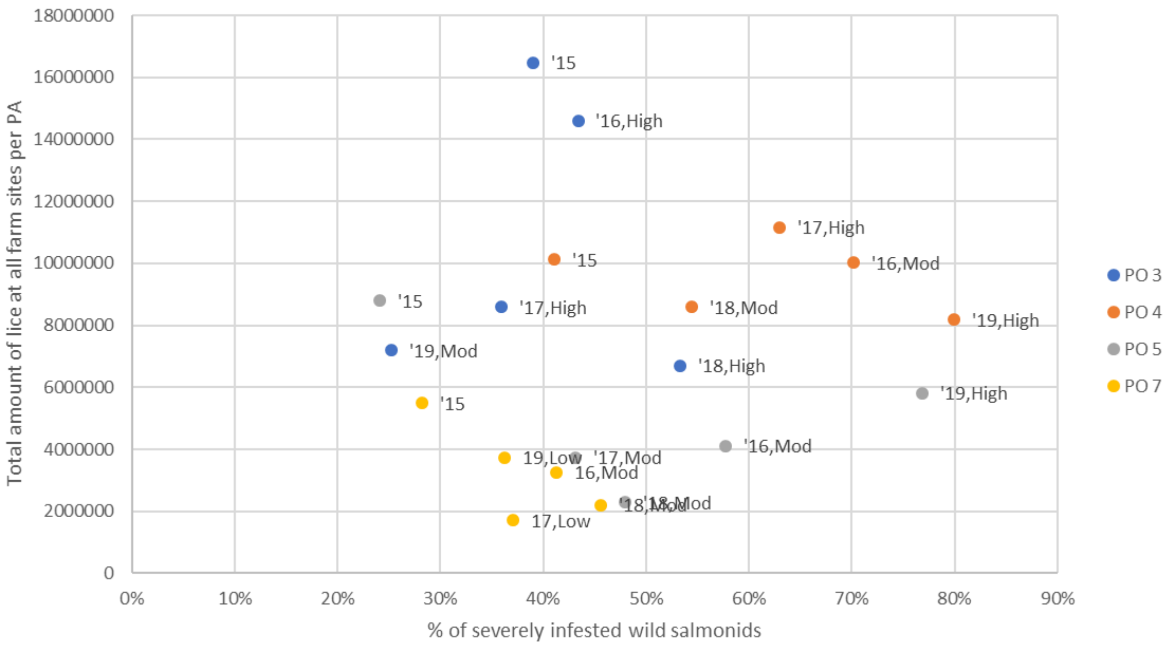
Figure 13. Correlation between share of sites with > 0.2 lice per fish, and share of infested wild fish for all sites, 2015–2019



Notes: Investigation of data from two years prior to the tightening of the lice threshold (2015–2019). Data labels are the expert group recommendation of the status in each PA.

Having found no positive correlation between successful lice compliance in the selected areas and the infestation pressure on the wilds salmonids, we now turn to the relationship between the total number of reported farm-lice within each PA and the data records on wild salmonids. From inventory data from each production site and corresponding average lice-level reports we can calculate the total number of lice within each PA. Does a high amount of lice at the farm sites within a PA affect the share of severely infested wild salmon? Again, as seen from Figure 14, there is no significant correlation indicating a connection between the totality of farm-site lice within a PA and the reported data on infested wild salmonids. For instance, in PA 3 in 2015, there were more than 16 million farm-site lice, but less than 40% of the wild salmonids were severely infested; in PA 4 in 2016, there were 40% less lice than in PA 3 in 2015, but the infestation pressure was significantly higher. Across all data points, the variables show only a weak positive correlation (0.07). Examining the PAs seperately for all years, we also find no significant positive correlation. In PA 7, we find a negative correlation coefficient of −0.77, indicating that there is less infestation pressure on the wild salmonids when the lice level is high—the oppostite of what might be expected.

Figure 14. Correlation between total number of lice in all farming sites in each PA and the corresponding share of infested wild fish, 2015–2019



Note Data labels are the expert group recommendations of the status in each PA.

As to the conclusions of the expert group, there is correspondance between the risk level and the total number of lice, with a correlation coefficient of 0.65. All the high risk indicators are thus above 5.8 million lice. Between the expert group's risk level and the share of severely infested wild salmonids we find a correlation coefficient of 0.48. Thus, the expert group's risk level is slightly more strongly correlated with the total amount of lice at the farm sites across the areas investigated, than the share of severely infested wild salmonids.

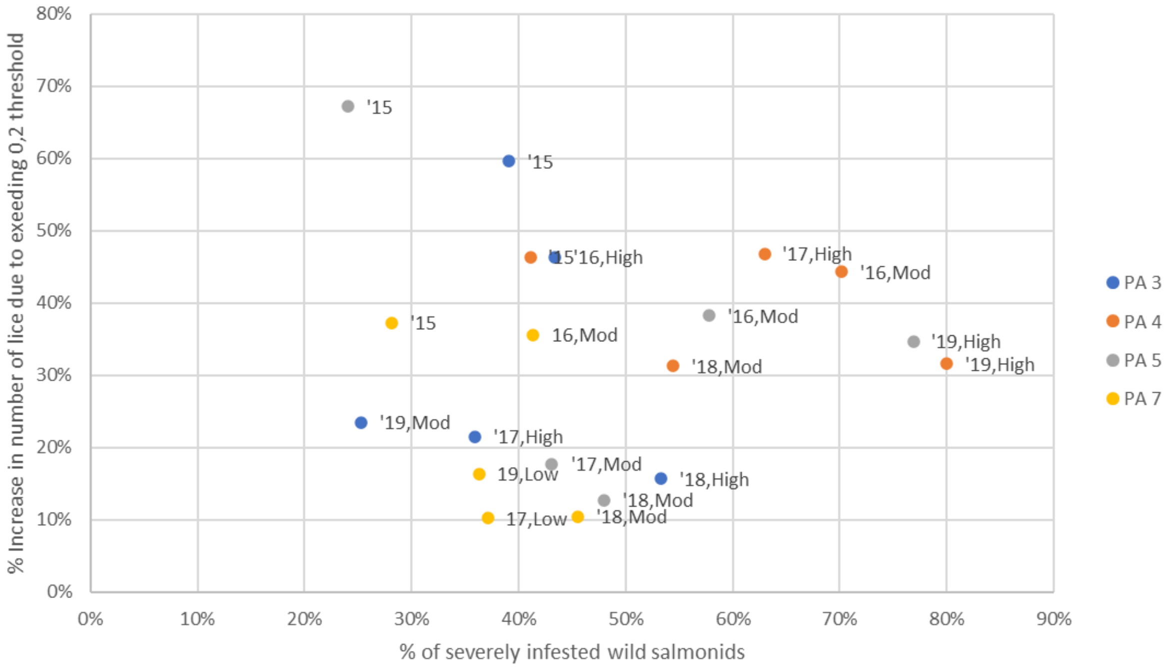
We find no significant relationship between the share of sites that maintain a low lice level, and severely infested wild salmonids in the PAs investigated. That applies also regarding the total number of lice at the farm sites.

We now turn to the relationship between greater amounts of lice occurring in each PA due to non-compliance with the threshold average of 0.2 adult female lice per fish, and the amount of severely infested wild salmonids. Do the greater numbers of lice due to non-compliance affect the wild salmonids?

As seen from Figure 15, in 2015 lice numbers were more than 55% higher in PAs 3 and 5 than what would have been the case if all sites had stayed within the 0.2 threshold. And yet, the impact on wild salmon was among the lowest of all the data points. In comparison, in 2018, there were only 10% more lice due to non-compliance for PAs 5 and 7, whereas the corresponding percentage of severely infested wild salmonids was higher. Thus, we observe no correlation between the increase in lice level at farming sites due to non-compliance with the 0.2 threshold, and the share of severely infested wild salmonids (0.00). Neither do each area in isolation show any positive correlation. We find a negative correlation for PA 4, 5 and 7 (between −0.37 and −0.49), indicating that the infestation pressure decreases when there is a higher level of lice due to non-compliance—which is also the opposite of what one might expect.

The relationship between the expert group’s risk status and percentage increase in lice is moderate (0.55), slightly lower compared to the previously examined variable, the total number of lice.

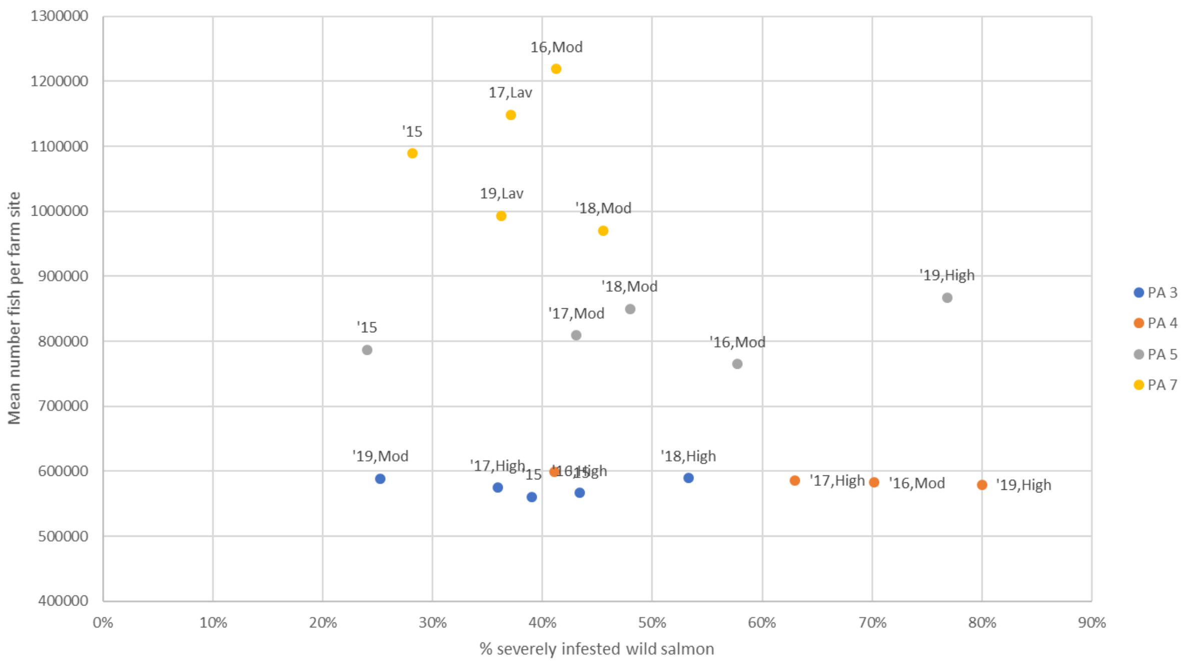
Figure 15. Correlation between percentage increase in lice due to exceeding 0.2 threshold total in each PA, and the corresponding share of infested wild fish, 2015–2019



Note: Data labels are the expert group recommendations of the status in each PA.

None of the farm-lice related variables examined above show a significant correlation with the share of severely infested wild salmonids. Thus, for the PAs investigated here, we find that lowering the lice threshold has no significant impact on the share of severely infested wild salmonids. The expert group evaluations of risk in the PAs, as noted, correlate strongly with our analysis of the NALO data when the areas are examined in isolation (less so for PA 4). However, when we assess all the areas together, only a moderate correlation is apparent. This could be due to geographical variables incorporated into the expert group models, such as the spatial distribution of sites (number, geographical location, and density of production sites), biomass, temperature, and water currents, which are parameters beyond the farmers' control. This gives rise to another important question: would regulatory measures targeting other such variables have a greater impact on mortality risk than does implementing overly strict lice thresholds at production sites, which also lessens fish welfare due to treatment intensity? For instance, as seen from Figure 16, which shows the average number of fish at each farm site, the lower-risk PA 7 has a higher number of fish at each site, than the higher-risk PA 3 and PA 4, which have a higher number of farm sites.

Figure 16. Correlation between mean number of fish per farm site in each PA and corresponding share of infested wild fish, 2015–2019



Note: Data labels are the expert group recommendations of the status in each PA.

Several studies of geographic locality structure have examined how the density and suitability of sites affect the profusion of lice (Ådlandsvik, 2015; Institute of Marine Research, 2020; Samsing et al., 2017; Skarðhamar et al., 2018). Research and development on closed or more contained production systems is also ongoing (see for instance CtrlAQUA, 2015)—which represents a possible, alternative solution (Liu et al., 2011). As noted, we find that some production sites are able to keep lice levels low with fewer treatments, whereas other sites have high numbers of lice despite large numbers of treatments. The increase in de-lousing actions by farmers to comply with the regulatory thresholds has lessened fish welfare and caused higher mortality rates among farmed salmon. Should, then, other regulatory instruments be pursued?

Across all the areas investigated, we find no obvious correlation between the share of severely infested salmonids and the share of farm sites kept within the threshold, the total number of lice or the increase of lice due to non-compliance. These preliminary findings indicate that lowering sea-lice thresholds in fish-farming sites may fail to lessen the mortality risk for wild salmon populations. Thus, the environmental effectiveness of setting strict, farmed-fish sea-lice thresholds may be limited unless accompanied by parallel measures. However, although we do not find significant correlations between compliance with strict thresholds and lice infestation pressure on wild salmonids, our conclusion should not be interpreted as justification for relaxing sea-lice control. Rather, our results call into question the environmental effectiveness of implementing strict thresholds without adequate, complementary measures that target other variables such as density and the spatial distribution and geographical localization of production sites.

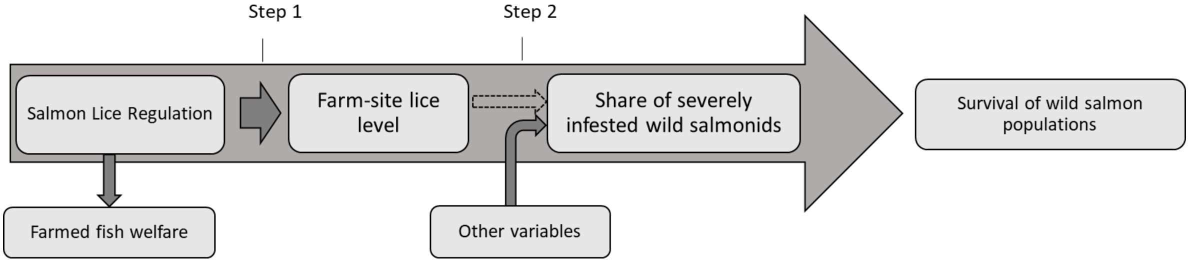
8. Conclusions

Protecting the health and survival of wild salmon populations is a main objective of sea-lice regulation for fish farms. This study has evaluated the environmental effectiveness of sea-lice regulation setting strict thresholds (0.5 and 0.2) for the average number of lice per farmed fish in selected production areas along the coast of Norway. From an environmental perspective, the success of such regulation does not depend on the average number of lice per salmon in the net pens, but on the degree to which compliance contributes to lessening the mortality risk for surrounding wild salmonid populations—and thus, ultimately, their survival.

We found that practicing a stricter lice threshold reduces the average number of lice per fish within farming sites. Thus, the regulation has had positive effects on lice-levels at production sites (Step 1, Fig. 17). However, in order to comply, many farmers have increased the use of mechanical de-lousing methods, which appears to bring on a new set of problems, including threats to farmed-salmon welfare and higher mortality rates in the pens. Furthermore, the seemingly gentler use of “cleaning-fish” is found to cause poor welfare and high mortality rates for the species used.

Our analysis shows that the environmental effectiveness of regulation has been limited or absent: successful compliance with sea-lice thresholds does not notably affect or lessen the share of severely infested wild salmonids (Step 2 in Fig. 17). We found no significant correlation between the proportion of severely infested wild salmon and (i) the share of sites that stay below the 0.2 threshold, (ii) the total amount of farm lice, and (iii) the greater numbers of lice due to non-compliance.

Figure 17: The Environmental Effectiveness of Salmon Lice Regulation



Other farm- and area related variables also affect the sea-lice infestation pressure on wild salmonids. These include the total biomass in an area, the density and the spatial distribution of fish-farming sites, the number and size of sites, as well as natural conditions such as sea temperature and water currents. Our results indicate that the environmental effectiveness of strict sea lice regulation will be limited, unless accompanied by parallel measures that target such other variables.

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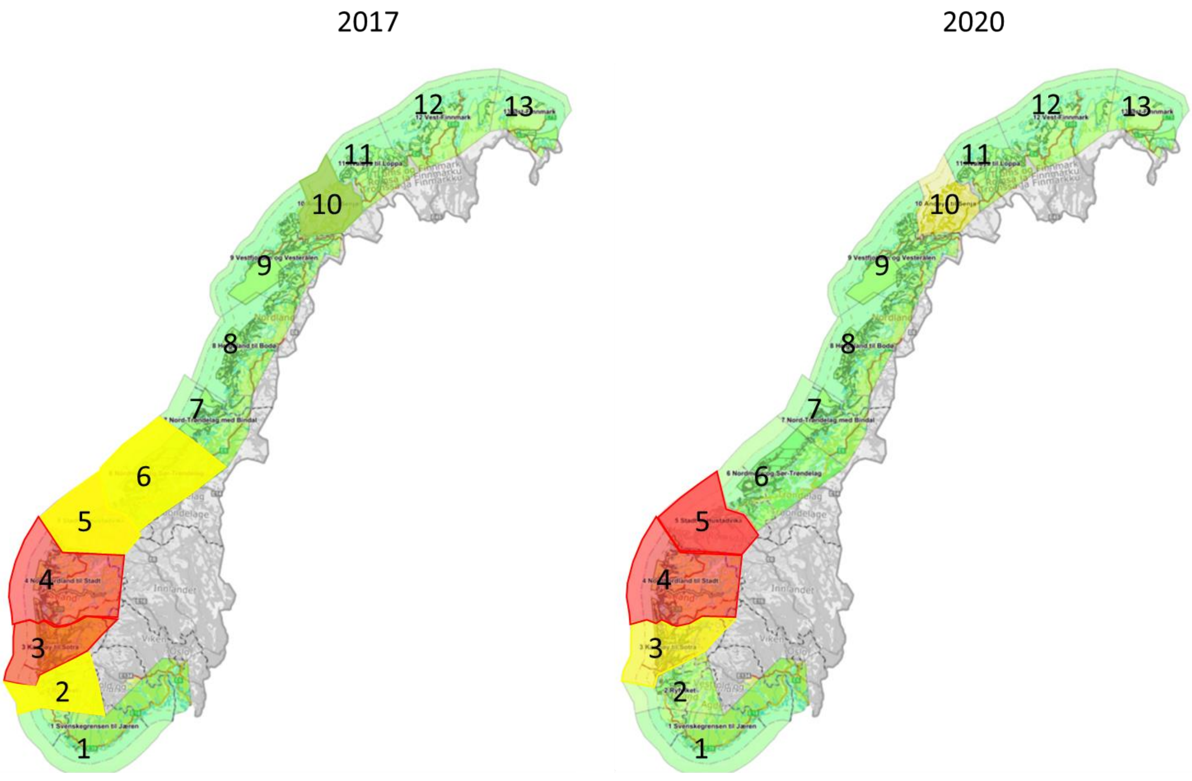
Appendix

On the Production Area (PA) selection process (see pg. 8):

Among the PAs given "green light" in both periods, our selection criteria include the size of the PA[10], the number of sites per km^2 and the ton of fish per km^2. Data from the Directorate of Fisheries, 2017. Relevant PAs for selection (PAs deemed "green light" both periods): PAs 1, 7, 8, 9, 11, 12, and 13 (Figure 1). The size of the PA 3, 4 and 5 ranges from approximately 4500 to 5200 $km.^2$ Of the PAs relevant for selection only PAs 1, 7 and 13 are within this range. The number of sites per km^2 in PA 3, 4, and 5 ranges from approximately 0.010 to 0.040. Of the PAs relevant for selection only PA 7 is within this range. The ton of fish per km^2 for PAs 3, 4 and 5 ranges from approximately 11 to 30. Of the PAs relevant for selection only PA 7 is within the range. Based on these criteria we evaluate PA 7 as most appropriate candidate.

Figure 1. Governments Traffic lights 2017 and 2020



[10] Size is here within the baseline, which is where all farm sites are located today.

Table 1. Statistical processing of data

	PA	Year	Month #	Week #			Formulas
Farm site data:							
Distribution of lice # in PAs	{3,4,5,7}	2015 to 2019		16 to 21	n= Farm Site #		Max.[L (n)]
Stock of salmonids	{3,4,5,7}	2015 to 2019	4 to 6		n= Farm Site #		Max. [S (n)]
Compliance	{3,4,5,7}	2013 to 2019		16 to 21	n= Farm Site #		A= Count if(L (n) >= 0,2) ; B= Count if (L (n) <0,2)
Overruns	{3,4,5,7}	2017 to 2019		16 to 21	n= Farm Site #		Count if L (n) >= 0,2
Mitigation measures							
Mechanical		2013 to 2019			n= Farm Site #		Count (mec(n))
Medical		2013 to 2019			n= Farm Site #		Count (med (n))
Biological		2013 to 2019			n= Farm Site #		DIV 2(Count (bio (n)))
Wild salmonid data:							
Share of severely infested wild salmonids	{3,4,5,7}	2015 to 2019		19 to 26	n = test locality per week	For every n	C (n) =N (n) * R
Toal per PA	{3,4,5,7}	2015 to 2019		19 to 26	n = test locality	For all n within each PA	Sum (C (n)) / Sum N(n))
Parameters:							
PA =	Production Area						
L =	Average number of lice per fish						
S =	Stock of farmed salmonids						
Mec =	Mechanical measures						
Med =	Medical measures						
Bio=	Biological measures						
N=	Total number tested wild salmon per locality						
R=	% over 0,1 rel.int. (reported share of tested salmon per locality per week with more than 0,1 lice per gram)						

Notes to Table 1: To find the highest lice level at each site during the critical period, we have used the maximum lice count and the corresponding maximum fish stock. The distribution of lice level for each PA was calculated by using the highest reported average lice count per fish during weeks 16–21 from each site. The stock of salmonids in each PA was calculated by using the highest stock of fish at each farm site during April–May each year (reported monthly, not weekly). Non-compliance/compliance was calculated by differentiating the number of reports of average number of lice per fish 0.2 or higher, and number of reports less than 0.2. The number of mitigation measures was calculated by differentiating the three different methods, and dividing the biological method by two, which was done to adjust for the reporting being based on the different species of cleaner fish (some report one species, others two or three). The share of severely infested wild salmonids per year was calculated by first categorize the test site data based on which PA it was enclosed by, and then calculating the overall reported share of tested salmonids with more than average 0.1 lice per gram fish of the total number of tested fish. The percentage increase in number of lice due to overruns was calculated by first filtering all sites which exceeded 0.2. We then calculated the number of lice for a hypothetical situation where these sites were kept within the threshold (at a level of 0.19). The difference in number of lice for the actual lice level and the hypothetical lice level could give us an impression of the increased number of lice due to overruns.

Table 2. Overview of average lice counts for the different Pas for week 16-21

	2015		2016		2017		2018		2019	
	Median	Max	Median	Max	Median	Max	Median	Max	Median	Max
PA 3*	0.16	0.20	0.12	0.19	0.09	0.11	0.08	0.11	0.08	0.11
PA 4*	0.11	0.13	0.11	0.12	0.11	0.22	0.11	0.13	0.09	0.11
PA 5*	0.16	0.20	0.12	0.13	0.13	0.16	0.08	0.13	0.16	0.17

Notes to Table 2: PA 3* refers to sites in the county of Hordaland, which is representative of PA 3; PA 4*, to sites in Sogn & Fjordane, representative of PA 4. PA 5* refers to sites in Møre & Romsdal, where there are slightly more sites than in PA 5, which might affect the numbers.

Table 3. Overview of tested wild salmonids

		Trawl data			Fish nets/traps			Both methods
		# Tested	# >0.1	% > 0.1	# Tested	# >0.1	%> 0.1	% >0.1
PA 3	2015	134	73	54 %	910	334.77	37 %	39 %
	2016	191	57.45	30 %	413	204.74	50 %	43 %
	2017	255	109.3	43 %	801	270.2	34 %	36 %
	2018	156	50	32 %	903	514.6	57 %	53 %
	2019	302	38.09	13 %	380	134.03	35 %	25 %
PA 4	2015	N/A	N/A	N/A	245	100.63	41 %	41 %
	2016	N/A	N/A	N/A	489	343.09	70 %	70 %
	2017	197	95.77	49 %	493	338.86	69 %	63 %
	2018	397	157.58	40 %	769	477.19	62 %	54 %
	2019	400	303	76 %	666	549.62	83 %	80 %
PA 5	2015	N/A	N/A	N/A	259	62.36	24 %	24 %
	2016	N/A	N/A	N/A	514	296.84	58 %	58 %
	2017	415	86.53	21 %	587	345.38	59 %	43 %
	2018	121	0	0 %	584	338.12	58 %	48 %
	2019	105	64.92	62 %	835	657.52	79 %	77 %
PA 7	2015	N/A	N/A	N/A	187	52.7	28 %	28 %
	2016	N/A	N/A	N/A	201	82.96	41 %	41 %
	2017	N/A	N/A	N/A	186	68.99	37 %	37 %
	2018	N/A	N/A	N/A	217	98.85	46 %	46 %
	2019	27	0	0 %	354	138.18	39 %	36 %

Table 4. Overview of Correlation Coefficients

		Correlation Coefficients				
Variable I	**Variable II**	**PA 3, 4, 5, 7**	**PA 3**	**PA 4**	**PA 5**	**PA 7**
% of farm sites exceeding 0.2	% infested wild salmonids	**-0.1441**	0.1522	-0.4644	-0.2734	-0.5079
Total amount of lice	% infested wild salmonids	**0.0705**	0.0816	-0.3309	-0.3578	-0.7666
% increase in lice due to exeeding 0.2	% infested wild salmonids	**0.0038**	-0.0285	-0.3712	-0.3927	-0.4949
Risk factor [1-3]	% infested wild salmonids	**0.4783**	0.8000	0.4894	0.9129	0.9093
Risk factor [1-3]	% of farm sites exceeding 0.2	**0.2595**	0.4209	-0.5893	0.2679	0.7057
Risk factor [1-3]	Total amount of lice	**0.6528**	0.3814	0.1521	0.8398	0.0042
Risk factor [1-3]	% increase in lice due to exeeding 0.2	**0.5472**	0.1609	0.098	0.4706	0.4705