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Governing the welfare of Norwegian farmed salmon: Three conflict cases

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ABSTRACT

To obtain insight into perceptions of how fish welfare and health is governed in Norwegian aquaculture, this study investigates three conflict cases: salmon lice, pancreas disease and farm siting. Using surveys and in-depth interviews, it highlights challenges and solutions as perceived from different professional groups. The results show that the current inflexible limit of the number of salmon lice permitted creates frustration, both among the farmers themselves and fish health personnel, and that many advocate means for making the regulations more in line with how much infection pressure a farm creates. The regulators acknowledge that upholding salmon lice regulations may diminish animal welfare. Also, farmers and fish health professionals are concerned about the welfare impact of risky delousing operations. Where pancreas disease is concerned, many express their incredulity that a clearly welfare harming disease is permitted to be endemic in parts of Norway, while a positive diagnosis outside the endemic zone will lead to the fish farmers having to slaughter their fish. The case of farm siting was responsible for less conflict than expected. Few expressed strong opinions, but some asked for an overall plan for farm positioning in order to limit spread of pathogens. All groups expressed a concern in that it is difficult to implement the necessary changes within the present framework. The overall problem seems to be that what is best for the single farmer or company in the short term, is often contrary to the common good and long-term benefit of the industry as a whole.

1. Introduction

Since the start in the early 1970′s the Norwegian salmon industry has developed from small scale, often family owned, fish farms to an intensive, technology and knowledge driven industry, dominated by large multibillion companies. The Norwegian salmon industry is regulated in a complex way by several sector authorities using a range of laws and regulations and guidelines, aiming to prevent negative external effects on other actors, but also to create positive effects like employment and tax income to society [1]. The current laws and regulations are a result of a long history of dynamic interactions between a growing and developing industry and changing politics from different governments, and their response to new scientific knowledge, and environmental, technological and economic challenges facing the industry [2].

Norway is today the world's leading producer of Atlantic salmon (*Salmo salar* L.). Annually, more than 300 million salmon smolts are released into the over one thousand fish farms along the long Norwegian coast, and about 1.3 million tonnes of salmon at a total export value of 68 billion NOK (7.5 billion USD) was produced in 2018 [3]. The industry does, however, face several challenges in terms of fish health and welfare, and negative environmental impact [4]. The industry needs to meet governmental goals that promote profitability, sustainability, the interests of coastal communities, and fish welfare and health [5]. Several regulatory authorities govern these goals. For example, the Norwegian Food Safety Authority governs fish health and welfare, and aims to limit the spread of pathogens, the Norwegian Environment Agency aims to limit harmful pollutants and waste products from fish farms, while the Directorate of Fisheries is in charge of long-term profitability through sustainable management of marine resources [6].

Although the industry is closely governed, large numbers of fish die during operations [7]. Fish welfare thus has a major potential for improvement. Fish welfare is a result, among other things, of the fish's health, environment, farming technology, organizational routines, and margins in production processes [8,9]. How fish welfare is governed in

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practice has not been studied previously, but the topics of fish welfare, regulations and governance have been explored separately [6,8,10–15]. The benefits, downsides and potential improvements in fish welfare governance might be revealed by the study of current conflicts in Norwegian salmon farming. The challenges of salmon lice (*Lepeophtheirus salmonis*), pancreas disease (PD) and suboptimal farm sites are all related to fish welfare, partly due to conflicting goals, such as industry profitability and protection of the environment. This study explores the views of Norwegian salmon farmers, fish health personnel and regulators about how the governance of salmon lice, PD and farm siting influence fish welfare. The study aims to identity what, if any, possible solutions exist to improve the governance of fish welfare.

Conflict 1 – salmon lice: Public governance of salmon lice permeates Norwegian aquaculture governance [16]. The Norwegian government recently divided the Norwegian coastline into 13 production zones and introduced the so called "traffic light system", where the impact of salmon lice on the wild populations determines in which zones the industry is allowed to grow (green), freeze production (yellow), or have to reduce production (red) [17,18]. Fish farmers spend substantial financial and manpower resources on monitoring, preventing and removing salmon lice [19–21]. The clearly defined salmon lice limits in the "Regulation on fighting salmon lice at aquaculture plants" [22] serves two purposes. These are; preventing farmed fish from becoming infested with salmon lice at levels that compromise welfare, and restricting the spread of salmon lice from fish farms to the wild population of Atlantic salmon and sea trout, in other words protecting and sustaining wildlife [6,23]. The limits vary according to smolt salmon migration periods: The limits are set to 0.2 average adult female salmon lice per fish between weeks 16 and 21, and to 0.5 adult female salmon lice outside these weeks for southern Norway, while the low 0.2 limit is set between week 21 and 26 for northern Norway (§ 8). The fish farm companies are obliged to monitor salmon lice levels and employ mitigating measures to avoid excess levels of lice. This can include use of cleaner fish to eat the lice off the salmon [24], preventive lice barriers like i.e. skirts or snorkels [25,26], giving medicinal feeds or bathing the fish with chemical therapeutants, thermal or mechanical delousing, i.e. using warm water (28–34 °C) or sea water flushing to detach the lice from the salmon [7], or early slaughter. Delousing is a significant expense for fish farmers in terms of direct costs [27], reduced growth [21,27], escapes of fish [28], fish mortality [7] and fish health [29], and although early slaughter can be the most welfare friendly strategy it will often mean significant less profit. When a farm exceeds the salmon lice limits, the Norwegian Food Safety Authority can respond with sanctions such as fines, and/or ordering the farm to perform the necessary measures to reduce lice levels, slaughter the fish, and ultimately reduce the biomass permitted at the site [6].

Here, there is a potential conflict between governing the inflexible salmon lice limit for the sake of the environment and wild salmonids, versus the welfare of the farmed fish, including cleaner fish welfare not covered in this paper, as well as occupational safety and other costs.

Conflict 2 – PD: Pancreas disease (PD) results in poor fish health and welfare [29], as well as economic loss to farmers [30,31]. It is well known that PD is a serious viral disease that reduces the production of digestive enzymes in the pancreas [32]. Sick individuals may suffer significant muscle damage, including damage to the oesophagus and heart muscles, in turn leading to reduced blood circulation [33]. The Norwegian Food Safety Authority's main tool to prevent further spread of PD is a system of zoning, see "Regulation on prevention, control and combatting pancreas disease (PD) in aquaculture animals" [34]. The regulation defines an endemic PD zone from the southern tip of Norway to Flatanger in mid-Norway (Fig. 1), where PD is tolerated. PD north or south of these borders is not tolerated, and detection triggers various preventive actions such as testing of neighbouring farms, control of movement of fish, or even emergency slaughter if the risk of spread of infection is deemed to be high. The endemic PD-zone is further divided in two zones according to virus strain. Salmonid alphavirus (SAV) subtype 3 is tolerated south of Hustadvika, while the less virulent subtype 2 is tolerated north of this border (Fig. 1). There have been discussions about whether zoning is a good strategy for fighting PD, and regarding the consequences of zoning for fish farmers. A recent study [13] found that farmers close to a zone border often have to bear an unfair proportion of the overall costs, and that identifying appropriate cost-sharing mechanisms is crucial to maintaining the support of farmers. Where animal welfare is concerned, PD is problematic in both its acute and chronic stages [8], as it can be long-lasting, and farming systems or farmers often fail to take care of individuals with significantly compromised welfare, who are seen as "loser fish" [9]. Infected fish typically stop eating, behave abnormally, and in many cases, mortality increases (Fig. 2).

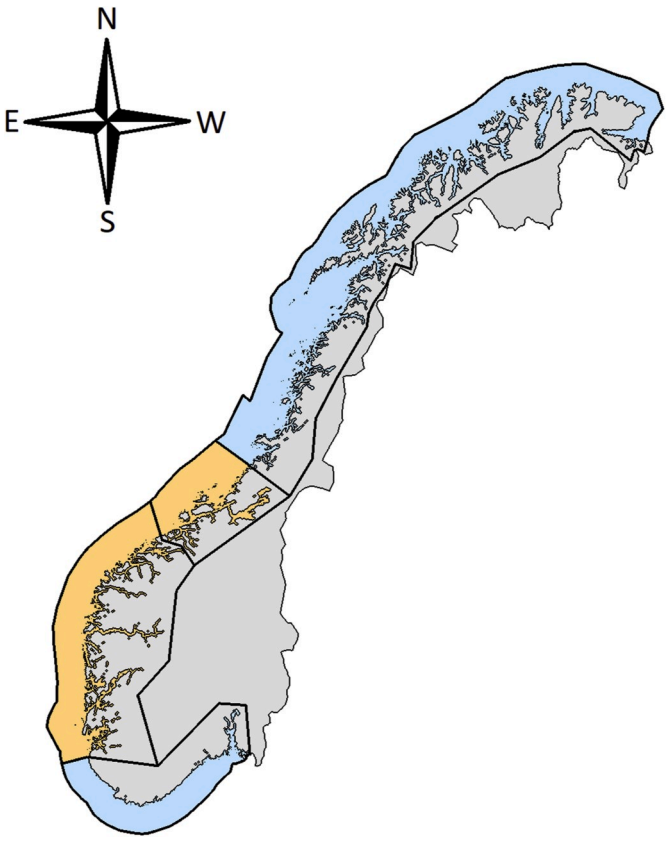

Fig. 1. Endemic PD zone where SAV is tolerated (orange) and the two surveillance zones (blue) north and south of the endemic zone. The endemic zone is divided (black line) north and south of Hustadvika, where SAV 3 is tolerated south of this border, and SAV 2 north of the border. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

There is a conflict in PD governance regarding long-term goals, i.e. whether to accept PD as an endemic disease that will remain or eradicate it. There are clearly different stakes for the producers outside the endemic zone (free from the disease) and in the endemic zone.

Conflict 3 – fish-farm siting: Fish farmers cannot freely select their farm locations, nor can they freely change the orientation and layout of existing farm locations to optimise fish welfare [6]. Where a fish farm is sited and how the sea cages are positioned relative to each other depends on a range of different local and national regulations [6,35–37]. Conflicting interests with ship traffic, fisheries, tourism, local population, etc., can make it difficult to locate the farms in sites with optimal water environment and minimum risk of receiving infections from neighbouring up-current farms [37–39]. For the fish farmer and the fish, good environmental conditions at the selected site are essential for fish welfare and production. Good conditions are characterized by stable

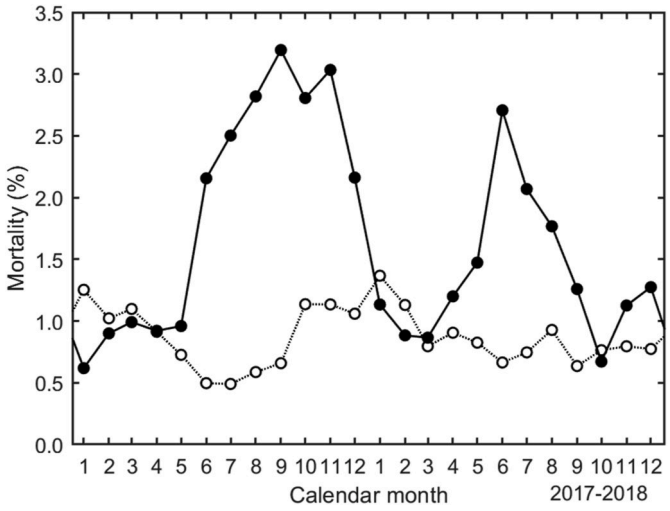

Fig. 2. Monthly mortality in endemic PD-zone for farms with diagnosed PD (solid line and closed circles) and for non-diagnosed farms (dotted line and open circles). Data: Norwegian Directorate of Fisheries and Norwegian Food Safety Authority.

currents that supply the fish with oxygen-rich water and remove waste, temperatures in the optimal range, and locations close to land or islands that protect against high waves and stormy weather [40]. In addition, connectivity with other farms should be low to reduce the risk of infectious diseases and parasites [41,42]. However, even though Norway has a long coastline, the industry view the lack of good new locations with low conflict level as one of their greatest challenges [36]. Furthermore, applying for a new farm location or making significant changes in the layout of an existing farm is a complex process administered by the respective County Authority, but involving also the local municipality, the regional offices of the Directorate of Fisheries and the Norwegian Food Safety Authority, the Coastal Administration, and the County Governor [6]. The fish farming company must meet the requirements of the different authorities on diverse topics such as clarification according to local area plans, shipping lanes, traditional fisheries, nature conservation, sufficient spread of faeces and feed waste, animal welfare and food safety. As a result, the fish farm location and its layout may not be optimal for fish welfare, and some farmers describe the process of applying for site changes as exhausting [39]. It should here be underlined, that the Aquaculture Act states that the application must meet the requirements of the Food Act, the Pollution Act and the Port and Waters Act [6]. In addition, the Regulations on the establishment and expansion of aquaculture facilities [43] specifies that the applications also must meet the requirements of the Welfare Act. The County Authority can therefore not approve applications not approved by the Norwegian Food Safety Authority, the Coastal Administration or the County Governor.

To investigate these three conflicts and fish welfare governance, a survey and in-depth interviews of key personnel were carried out. The research questions were: How is the governance of salmon lice, PD and farm siting viewed by fish farmers, fish health professionals and regulators? What are their suggested improvements? The results are presented in sections 3, 4 and 5. Section 6 comprises a discussion of the three cases, and Section 7 concludes what they reveal in terms of improving the governance of fish welfare.

2. Material and methods

This study includes survey and interview results. The study was approved by the Norwegian Social Science Data Services (enrolled 2017-03-16). All respondents and interviewees participated voluntarily, received written information and explicitly agreed to participate in the study.

2.1. Survey

The survey about governance of fish health and welfare was sent electronically in April 2018 to Norwegian fish farms and public agencies involved in aquaculture governance. The survey was developed in the survey programme SelectSurvey, which collected the respondents' IP-addresses, but otherwise ensured the respondents' anonymity. Some respondent groups and companies received one or more reminders before the survey was closed in November 2018. The survey was distributed via contact persons in companies and public agencies that were asked to forward the survey to relevant personnel. It is therefore not possible to calculate response rate.

The questionnaire contained similar questions regarding salmon lice, PD and farm siting, mainly with answer alternatives on a 5-point Likert scale. The aim was to compare the respondents' experience across areas. The first question addressed the impact on fish welfare of the public regulations of 1) salmon lice, 2) PD and 3) farm siting. The next two addressed the collaboration, first between the industry and authorities and then between different authorities, for each of the cases. The respondents were asked about their experience with the regulations with regard to the three specific topics and their impact on fish welfare:

1a: Is it your experience that the public regulations of [salmon lice/PD] improve fish welfare?

1b: Do you experience that the regulators take fish welfare and health into account when considering farm siting?

2: How good is the collaboration between the industry and the regulators regarding [salmon lice/PD/farm siting]?

3: How good is the collaboration between the governmental agencies regarding [salmon lice/PD/farm siting]?

In the analysis, the results of the five step Likert scale responses are collapsed and simplified into three levels: 'poor', 'neutral' and 'good', where 'poor' includes the two lowest levels, 'good' the two highest levels and 'neutral' the middle level. This is done in order to make the tables in the result section easier to read.

At the end of each survey topic, textboxes allowed respondents to suggest potential improvements for the regulations: "*Do you have suggestions improving collaboration and regulations regarding [salmon lice/PD/farm siting]? Please elaborate*". The answers to these open-ended questions are varied, lengthy and include a wide range of topics. In the analysis, these text sequences are treated as interview data since they are similar to the transcribed interview data and reflect on the same questions as the interviewees did (see more in Section 2.2).

The survey targeted company managers, administrative personnel, farm operational personnel, and fish health personnel in fish farming companies, and regulators in the Norwegian Food Safety Authority and the Directorate of Fisheries. The survey respondents self-identified their profession as either farm company manager or administrator, farm operational personnel, farm operational manager, farm responsible for fish health/biology or regulator.

A total of 84 valid responses to the survey were received, 'valid' meaning that they had completed the whole survey and provided information about their position. Nineteen respondents were fish farm company managers or administrators, 11 were fish farm operational personnel, 20 were fish farm operational managers, 17 were farm fish health personnel and 17 respondents were regulators.

2.2. Interviews

The data gathered for the study also included semi-structured interviews of 27 persons regarding fish welfare and the three conflict cases, among other topics. The interviews, which were carried out in 2018, were held with fish farm managers, operational personnel, fish health personnel and regulators from the Food Safety Authority (operating in areas both with and without PD). Some were done as group

interviews.

Interview guides adapted to each profession category were used as a basis for the interviews. The guide for fish farming personnel consisted of six parts; 1) Work position and relationship to fish welfare, 2) Running of the farm and daily work operations, 3) Experiences with public regulations, 4) Experiences with the regulators, 5) Fish health and welfare competence and 6) Suggestions for improvements. The guide for regulators had five parts: 1) Work position and fish welfare, 2) Experiences with the industry, 3) Experiences with public regulations, 4) How the regulators work in relation to fish welfare and health and 5) Suggestions for improvements.

In addition, four interviews specifically covered borders between different zones and their respective PD regulations. Two of these were with fish health personnel employed in aquaculture companies, one from the Food Safety Authority with background as fish health personnel. The fourth interview took place with a manager of an aquaculture company with farms all along the Norwegian coast. One of the fish health personnel from the industry represented a company with farms both in the endemic PD zone and outside it, and the other a company from the PD-free zone near the border of the endemic zone.

The interviews were carried out by one or two researchers, either at the interviewees' workplace or by phone. Each interview was transcribed, either directly by one of the researchers, or recorded for later transcription.

2.3. Combined analysis

The reporting of results in Sections 3-5 combines the two qualitative data sources: the interview data and data from the open-ended questions in the survey. These two sources are different in form, but similar in content. The form of the interviews was oral, but the transcriptions are textual and thus similar to the survey respondents' answers to the open-ended questions. The content is also comparable, as both interview guide and open-ended survey questions asked the informants to reflect on the same topics. The combined qualitative data gave a broader range of data, which allowed the analysis to detect the patterns presented in Sections 3-5.

The current methodological approach thus employs data triangulation, as both qualitative and quantitative data are used in the analysis. In the discussion (Section 6), the qualitative and the quantitative data are discussed with the support of earlier research. Combining these data sources in reporting and analysis strengthens the reliability and validity of the results.

2.4. Limitations of the study

As fish welfare governance is the subject, a potential bias towards personnel that have much knowledge about these issues may well exist, and the results might have been different if other personnel had been studied. For *interviews*, fish farm personnel were selected based on their locations and not on reported interests in fish welfare issues, while regulators were selected because they worked with salmon lice, PD, siting or fish health or welfare. The *survey* was distributed widely, but the actual respondents may have had a particular interest in fish welfare governance, and the results may be biased towards those who are more interested in fish welfare than average. The survey respondents did not state which region they operate in. This limits the results, especially in the PD case where it would be valuable to know if the answers came from personnel operating in zones with or without PD. Although total number of respondents to the survey where relatively high, within each professional group the number of respondents could be as low as 11. This limits the value of the quantitative results per group. However, the comments from the open-ended questions in the survey where similar to those of the 27 interviews (see below). The same points kept being repeated. This suggests representativity in responses, and that increasing the number of respondents would only results in more of the same types of answers. Similarly, after several interviews the responses also became repetitive with few new points, suggesting data saturation was achieved.

3. Results about salmon lice governance

3.1. Quantitative results about salmon lice regulations

Sixty-six percent of the respondents stated that today's governance of salmon lice had a limited effect on improving fish welfare, while 23% held that it led to improved welfare (Table 1). Salmon lice governance was valued as good for welfare by 37% of the fish farm managers, but by only 12% of the farm fish health personnel.

Fifty-six percent of the respondents answered that the collaboration between the regulators and the industry regarding salmon lice was good (Table 2). The fish health personnel were most critical, with only 29% rating the collaboration to be good, while 68% or more of the fish farmers rated the collaboration as good. Only 6% (1 of 17) of the farm fish health personnel considered the collaboration between different regulators as good (Table 2).

3.2. Qualitative results about salmon lice regulations

This section reports the joint results from the open-ended questions in the interviews and survey regarding views on how the salmon lice regulations influence fish welfare.

Most participants expressed some concern that the salmon lice regulations, and the interpretation of the regulations, could jeopardize the welfare of the farmed fish. A frequently mentioned point made by farm personnel was that the weekly mandatory salmon lice counts led to unnecessary handling of the fish, even in periods with very little or no salmon lice.

All respondents viewed delousing as harmful to the fish, especially the methods using warm water or mechanical delousing. Representatives from all groups voiced a need to balance between an inflexible salmon lice limit and the current stressful and risky delousing methods. Many were frustrated with the requirement to delouse fish that could have been subject to other measures to reduce lice levels. They typically stated that due to the salmon lice limit, the fish sometimes undergo delousing operations even though they would soon be lice free because of 'natural conditions' or other means. One of the fish farmers stated:

> *It shouldn't be necessary to delouse the fish when we know that the salmon lice will be gone in a few weeks when the site will be dominated by brackish water that kill the lice.*

Many respondents also called for adapting the salmon lice limit more in line with how much infection pressure the farm generates and the risk to the wild fish, for instance, by increasing the salmon lice limit further during winter or by having a limit that reflects the number of fish at the farm.

Many of the fish health personnel saw the salmon lice limit as too rigid and wanted more dialogue with the Norwegian Food Safety Authority. They also asserted the need for more discretionary space to apply their own professional judgement, in order to decide whether to perform delousing or not. They emphasised that they often experienced a dilemma between fish welfare and having to authorise delousing to keep the farm below the limit. Some were frustrated by farmers who asked them to prescribe risky treatments – for instance thermal treatment at temperatures above 34 °C or treating weak fish. A commonly held view among fish health personnel was that the salmon lice governance should to a greater extent seek to reward farmers who employ methods and procedures that minimize salmon lice infestation.

Informants from all groups voiced suggestions for improvements. They wanted more room for expert judgement, and a lice limit more attuned to the time of year and use of cleaner fish, instead of a specific

Table 1
Number of responses in each grading level per professional group to the question "To what extent is fish welfare improved by current regulation of salmon lice?". Total number of respondents was 83.

Question	Grading	Farm op. personnel	Farm manager	Company man. or adm.	Farm fish health p.	Regulator	Total
To what extent is fish welfare improved by today's governance of salmon lice infestations?	Poor	8	12	10	14	11	55
	Neutral	0	0	4	0	2	6
	Good	3	7	4	2	3	19
	Don't know	0	0	1	1	1	3

Table 2
Number of responses in each grading level per professional group to questions about collaboration regarding salmon lice between industry and the regulators, and between different regulators. Total number of respondents was 84.

Question	Grading	Farm op. personnel	Farm manager	Company man. or adm	Farm fish health p.	Regulators	Total
How good is the collaboration between the industry and the regulators regarding salmon lice?	Poor	2	2	3	6	3	16
	Neutral	0	4	3	5	6	18
	Good	8	14	13	5	7	47
	Don't know	1	0	0	1	1	3
How good is the collaboration between different regulators regarding salmon lice?	Poor	4	3	5	5	6	23
	Neutral	1	7	3	5	9	25
	Good	3	5	6	1	2	17
	Don't know	3	5	5	6	0	19

upper salmon lice limit. Some mentioned how it used to be easier to get acceptance for delays or to get dispensation from delousing earlier, and that this still depends on the particular Food Safety Authority representative. They also noted that there are different practices among regulators from different regions, a practice that creates confusion. Fish farm managers typically called for more meetings and arenas for coordination between the regulators and the industry, and between farmers within a region.

Some of the representatives from the Norwegian Food Safety Authorities expressed frustration of how difficult it is to find perfect solutions since the industry is so large and have so many farm localities. They agreed that the inflexible lice limit could be a problem, but also pointed out that some farmers waited until they reached the limit to act, while in their opinion, the farmers should have started preventive and mitigating actions before. They also pointed out that for regulators it can sometimes be difficult to know when to sanction against a farmer because of fish welfare, because the regulations lack a precise definition of what poor welfare constitutes.

4. Results about PD governance

4.1. Quantitative results about PD

Regarding pancreas disease (PD), 43% of the respondents held that current regulations had a limited effect on improving fish welfare, while 31% stated that it had a good effect (Table 3). On this topic, the farm fish health personnel were the most sceptical, while the operational personnel at the farms were the most positive, with farm managers and administrative personnel in the middle. Interestingly, the regulators were highly divided, with 41% answering that the effect was poor, 12% neutral, and 35% good (Table 3).

Collaboration between the industry and the regulators was reported as good by 64% of the operational personnel and 45% of the farm managers (Table 4). However, among farm fish health personnel and regulators, only 18% regarded it as good, while 41% saw the collaboration as poor. Responding to the question about collaboration between industry and regulators, the farm fish health personnel were even more sceptical, with 47% rating collaboration as poor and only 6% (1 of 17) as good (Table 4).

4.2. Qualitative results about PD

This section reports the joint results from the open-ended questions in the interviews and survey regarding views on PD regulations.

In all the professional groups, some expressed incredulity that a disease that impoverishes fish welfare is permitted in one part of Norway and not in others. Related to this, they identified three problems causing unequal treatment and deterioration of fish welfare.

Firstly, the governance regime implies that fish farming can place a different value on fish welfare in zones with and without PD. The governance regime accepts lower fish welfare for the farmed fish in the south of Norway, since endemic PD is accepted there (and PD is an obvious threat for fish welfare). However, according to the PD regulations, fish farms far from areas with PD must still submit monthly PD samples. Retrieving samples from apparently healthy fish is seen as reducing fish welfare, just as with salmon lice counts in periods with few

Table 3
Number of responses in each grading level per professional group to the question "To what extent is fish welfare improved by current PD regulation methods?". Total number of respondents was 84.

Question	Grading	Farm op. personnel.	Farm manager	Company man. or adm.	Farm fish health p.	Regulator	Total
To what extent is fish welfare improved by current PD regulation methods?	Poor	2	8	9	10	7	36
	Neutral	2	5	4	2	2	15
	Good	5	6	4	5	6	26
	Don't know	2	1	2	0	2	7

Table 4
Number of responses in each grading level per professional group to questions about collaboration regarding PD. Total number of respondents was 84.

Question	Grading	Farm op. personnel.	Farm manager	Company man. or adm.	Farm fish health p.	Regulator	Total
How good is the collaboration between the industry and the regulators regarding PD?	Poor	1	6	4	7	7	25
	Neutral	1	1	5	6	5	18
	Good	7	9	6	3	3	28
	Don't know	2	4	4	1	2	13
How good is the collaboration between different regulators regarding PD?	Poor	2	6	3	8	4	23
	Neutral	1	1	5	5	8	20
	Good	5	6	4	1	1	17
	Don't know	3	7	7	3	4	24

lice.

Secondly, the PD zone governance is believed to result in unequal treatment of companies. Some fish farmers outside the PD zones pointed out the unfairness associated with the regulations since they have to slaughter the fish in the case of PD, while farms within the PD zones can carry on as normal. Furthermore, fish farmers in the border zones must absorb the extra cost of maintaining the PD-free zone. Some farmers also pointed out that PD leads to unnecessary costs for the whole industry and suggested that perhaps a better strategy for the whole of the industry would be to get rid of the disease entirely.

The third, and most frequently mentioned concern, was that the current governance system is incapable of stopping the spread of the disease. Many respondents requested an improved and better coordinated "stamping out" strategy with an ultimate goal of eradication. Both regulators and fish farm respondents agreed that a strategy that aimed at eradicating PD in the endemic zone would be the right thing to do to safeguard fish welfare. One of them said:

To accept PD is the same as accepting poor fish welfare.

Some of the regulators agreed on the PD governance problem areas mentioned above, while others defended the regulations, and stated that:

PD is impossible to eradicate at the moment, the infection pressure of SAV is simply too massive, and a strategy to eliminate PD from southern Norway is impossible before we have an effective vaccine.

These descriptions of the problematic aspects of the regulations were reflected in the annoyance and mistrust of the PD regulation among many of the respondents. Fish farming companies and fish health personnel both suspected the regulations being based on an inadequate knowledge base and claimed there was much room for improvement. Some of the fish farmers also had difficulties in understanding the PD regulations, and said they were given different interpretations by different regional offices of the Norwegian Food Safety Authority.

Representatives of several of the groups made suggestions for improvements in PD governance. The most fundamental suggestions centred on the elimination of PD endemic zones. Some also suggested stricter restrictions on fish transport and a ban on open waiting cages outside the slaughterhouses in order to prevent the spread of PD.

5. Results about fish farm siting

5.1. Quantitative results about siting

Forty to sixty-nine percent of the farm personnel, farm managers, administrative personnel and farm fish health personnel experience that regulators *do* consider fish welfare and health regarding farm siting to a 'good' degree, while only 18% of the regulators were of this opinion (Table 5). The rest of the regulators either selected 'Don't know' or 'Neutral'.

More than 60% of the farm managers, company managers and administrative personnel were positive to cooperation between the industry and the regulators, while only 20% of the farm operational personnel and 24% of the farm fish health personnel were of the same opinion (Table 6). The results were similar for the question about collaboration between different regulators regarding farm siting, but interestingly 4 more of the 17 regulators selected 'Poor' to this question (Table 6).

5.2. Qualitative results about siting

In the interviews and open-ended survey questions, the relationship between fish welfare and fish farm siting turned out to be looked upon as a different type of conflict than the controversies over salmon lice and PD governance described above.

In general, there were few differences between the respondent groups on this matter. They mostly underlined a common problem: when fish farm siting conflicts with other stakeholders and groups in society this can result in sub-optimal siting. The operational personnel at fish farms expressed that even if they would not say that the site was optimal, they accepted the conditions and worked with these as a given. They described that most sites have healthy fish in some years and suffer from diseases in others. However, fish health personnel, regulators and managers hypothesised that differences in environmental qualities (i.e. currents, temperature, salinity, etc.) of sites can partly account for differences in fish mortality.

Some of the respondents expressed a sentiment that the siting of fish farms is too much governed by trying to avoid conflict with other interests in the coastal zone, such as wild catch fishing, tourists, environmentalists and others. According to these respondents, the results is

Table 5
Number of responses in each grading level per professional group to the question "Do you experience that the regulators take fish welfare and health into account when considering farm siting?", by personnel type. Total number of respondents was 82.

Question	Grading	Farm op personnel	Farm manager	Company man. or adm.	Farm fish health p.	Regulators	Total
Do you experience that the regulators take fish welfare and health into account when considering farm siting?	Poor	1	4	3	1	0	9
	Neutral	2	4	5	4	7	22
	Good	4	10	10	11	3	38
	Don't know	3	2	1	0	7	13

Table 6
Number of responses in each grading level per professional group to questions about collaboration regarding siting between industry and the regulators, and between different regulators. Total number of respondents was 83 and 82, respectively.

Question	Grading	Farm op personnel	Farm manager	Company man. or adm.	Farm fish health p.	Regulators	Total
How do you perceive the collaboration between your company and the regulators regarding farm siting?	Poor	2	3	2	2	2	11
	Neutral	1	4	4	6	8	23
	Good	2	13	12	4	7	38
	Don't know	5	0	1	5	0	11
How do you perceive the collaboration between different regulators regarding farm siting?	Poor	1	2	3	2	6	14
	Neutral	2	4	5	6	4	21
	Good	2	9	9	3	7	30
	Don't know	4	5	2	6	0	17

that some fish farms are placed in areas which are sub-optimal. Both fish farm managers, fish health personnel and regulators claimed that fish farm siting at times can be traced to historical isolated decisions and events, and that these, over time, have contributed to a site structure that should be improved.

Most of the comments in the interviews and the survey indicated that the siting governance could be improved. For example, new farms should not be placed so that they clearly influence already existing farms, to hinder spread of diseases. The participants in the study called for improvements in current area plans in order to ensure that regard for fish health and welfare is more prominent at an early stage in planning, when the municipality designates areas suitable for aquaculture. Some proposed that the suitability of a site in terms of fish health and welfare should be determined at an early stage, and before too many resources are invested in the application process. It should also be easier to modify the moorings of a site if it becomes clear that conditions would be much better just a short distance away.

Although many of the respondents had suggestions for how fish farm siting could be improved, they realised that there would be problems in implementing these changes. They emphasised that the Norwegian coastal governance and fish farming industry have their own structures and traditions, which would probably lead to a new siting policy being met with resistance.

6. Discussion

This section starts by discussing the three conflicts of salmon lice, PD, and fish farm siting separately, before concluding with a general discussion about how these conflicts relate to fish welfare and improvements in governance.

6.1. Governance of conflict 1 – salmon lice

There is an obvious conflict regarding salmon lice governance, and fish farmers have strong negative opinions regarding the inflexible salmon lice limit. The results of the survey and the interviews can be summarised as a general frustration from the industry that the salmon lice regulations lead to too frequent handling of the fish (during salmon lice counting and delousing operations) and from the regulators that the industry is powerful and the problem so complex that it is difficult to find optimal solutions. It was widely held by all groups that the governance of salmon lice did little to improve the welfare of the farmed salmon.

Some participants regarded it as unnecessary to delouse the salmon when lice would soon disappear due to the fjord becoming brackish, or due to other measures. It has been shown that high levels of meltwater from the snow will kill the salmon lice [44]. However, it is difficult to know exactly when this will happen, and the effect on the lice depends on how brackish the water will be, how deep it will go, and how long the conditions will last. Furthermore, the cleaner fish that are used to graze salmon lice off the salmon primarily feed on larger lice rather than the juvenile stages [45,46]. Thus, the cleaner fish need some time to catch up in cases of sudden increases in the number of adult female salmon lice. However, in sea temperatures above 10 °C, female salmon lice will produce a new set of egg strings in less than a week [47]. Delaying treatment when the temperature is high will therefore lead to a significant release of eggs. However, the eggs develop relatively slowly during the winter [47]. This is also the time of year when handling of the fish is most risky for the fish [8]. For this reason, a certain leeway in delaying treatment during the winter can be argued for.

In the survey, both administrative personnel and managers at fish farms requested alignment of the lice limit, infection pressure and the risk to the wild fish. It is well known that salmon density dilutes lice loads and thereby the counts, but not infection success [48]. Or in other words, a net-cage with 10 000 salmon will be infected by similar numbers of salmon lice as if there had been 100 000 salmon in the cage, but the average number of lice will be ten times as high. From an infection pressure standpoint, therefore, it would make more sense to regulate salmon lice on the basis of number of adult females on the site rather than of on the average number of salmon lice per fish.

Many farmers were concerned that the lice counts themselves harmed the fish. The fish need to be sedated and handled carefully during counting, which requires competent personnel. It is well known that handling salmon out of water in low air temperatures can be extremely harmful for the fish [8]. Perhaps as a reaction to this, in 2019 the Food Safety Authority opened for dispensation to the rule of manual salmon lice count and accepted that these may be replaced by automatic lice counting by underwater camera. This could provide a solution to the welfare problems associated with lice counts. Interestingly, none in the survey or interviews argued that euthanizing the lice counted individuals could be better for welfare, highlighting that euthanizing even a smaller proportion of the fish is often not even considered.

A more flexible salmon lice limit, as advocated by many of the respondents, would present new challenges for both regulators and the industry. It can for example easily lead to disagreements between regulators, farmers and fish health personnel on whether a decision to utilise this flexibility and postpone delousing is correct or not. It also can challenge the entire fish farm industry if more lax regulations exacerbate the salmon lice problem. In a strictly economic perspective, fish farms can save significantly if they delay and skip a delousing event or two in the course of a production cycle. A recent study [49] found that isolated farms can profit by increasing the treatment threshold to as much as 5-10 adult female salmon lice per fish before the cost of having salmon lice becomes greater than the benefit of postponing treatment. However, for fish farms that can infect each other with salmon lice, the optimal threshold is as low as 0.1 adult female salmon lice per fish. This is often referred to as the "tragedy of the commons" [13,49], where the individual farmers have incentive to disregard regulation at the expense of others. The term "tragedy of the commons" describe a situation in a shared-resource system (here the sea water) where individual users act

according to their own interest contrary to the common good.

Both fish farmers, fish health personnel and regulators express care and concern for the farmed fish and the environment, but they sometimes disagree on the measures needed to achieve it and what to prioritise. The interviews and the responses to the survey showed that the fish health personnel sometimes felt caught in the middle, between fish farmers and regulators, within their role as prescribers of medicinal and non-medicinal treatments and as a professional group advocating animal welfare. For example, when the average lice numbers on a farm are just over the salmon lice limit, the farmers and fish health personnel may sometimes want to prioritise fish welfare and not order a risky delousing. Or, in cases where the fish health professional would want to recommend early slaughter, but at the same time know that this will mean substantial economic loss for the farmer. Some of the respondents also pointed out the contradiction in adding cleaner fish in order to fall below the limit often means subjecting the cleaner fish themselves to low welfare conditions. Moreover, the regulators are aware that salmon lice regulations can take precedence over animal welfare. This is an important topic for further research.

6.2. Governance of conflict 2 – PD

Several respondents from all groups questioned the PD zoning system, which specifies where PD is allowed, and where PD-infected fish must be immediately removed. It is well known that PD spreads via ocean currents [50], and there is general agreement that slaughtering sick fish is a necessary measure to stop the spread of the disease. The conflict concerns the unequal treatment of fish farms since only fish farmers outside the PD zone have to bear this cost [13].

In addition, the informants underline that accepting PD in the PD zone means accepting an increased risk of poor welfare for the fish in these zones. This gives unequal welfare standards along the coast (as is documented in Fig. 2, and by Ref. [29]).

The mandatory tissue sampling of apparently healthy fish was viewed as unnecessary by several of the respondents. They argued that it should not be necessary to sample for PD far from the PD zone unless the fish farm has received fish from the PD zone. However, live-fish shipping has been linked to PD transmission [51,52], and the PD viruses can survive for several weeks [52,53] and may be carried over long distances by ocean currents [41,50]. Historically, there have been sporadic occurrences of PD outside the PD zone, most probably due to long-distance shipping of infected fish [13]. Although transport is regulated in order to limit the spread, it is possible that viruses spread far beyond the endemic zone. Thus, the welfare cost of the obligatory monthly screenings may be a small price to pay to prevent further spread. Mapping virus movements may also be a first step in a future more active eradication plan.

Several of the respondents suggested that PD should be eradicated along the entire Norwegian coast. They were not satisfied with the regulations because they negatively affect the fish in the PD zones, and several wanted the governance of PD to be uncompromising regarding fish welfare. As pointed out in the methods section, this study is biased towards fish welfare, as the people who took the trouble to answer the survey probably have a more than average interest in fish welfare, and since the interviewed regulators were selected because of their interest and competence in fish welfare. However, one of the regulators held that banning PD along the entire coast is impossible before effective vaccines, or PD-resistant salmon [54], are developed. However, many want to work with the aim to eradicate PD completely in Norwegian waters. Experience from stamping out PD outside the endemic zone [13] support the argument that this can be done. How long it takes would depend on the industry and the regulators, but at the speculative level, eradication within ten years could be a realistic goal if the intentions are strong and clear, and collaboration is good.

The eradication of PD is suggested to begin for instance with gradually moving the PD zone borders or increasing the size of the "buffer-zones" around the borders. Screenings of wild salmon and trout indicate that very few wild salmon and no wild trout are infected [53] and in collaboration with the farmers, the Norwegian Food Safety Authority has managed to eradicate one of the PD viruses from a fjord area. This makes it reasonable to assume that PD can also be eradicated in larger areas, but at a substantial cost [13]. One of the suggestions from the survey was to create a fund for covering such expenses by the industry as a whole and not individual fish farmers.

6.3. Governance of conflict 3 – fish farm siting

Siting is a somewhat different type of governance conflict than the cases of salmon lice and PD. Here, few of the informants disagreed with the others. It seems that everyone involved in fish farming and governance have the same aim – to find more suitable, and preferably optimal, fish farm sites. Most of the fish farm managers have positive experiences regarding siting governance. They were also satisfied with the collaboration with regulators in siting cases, and more so than in the governance of salmon lice and PD. One explanation could be that they obtained the sites they want, but this is very unlikely, as there is a lack of good fish farm sites [36,38]. It therefore seems that the fish farmers understand the complexity involved in balancing optimal conditions for the fish and heeding the interests of all the other stakeholders.

The operational personnel at fish farms were more neutral towards the siting governance. They described how they saw the site as 'given'. They were satisfied to have a site at all. Operational personnel are rarely involved in the strategic decisions regarding siting. Many fish farmers possess expert knowledge about their site, but do not have the overview and potential to systematise their knowledge across sites. However, some do relate the site conditions to a potential factor in mortality rates.

Regulators were also predominantly neutral to the siting governance. This might be because the current system leads to limited availability of potential new sites, and the inflexibility to change existent site licenses.

The fish health personnel perceived the siting governance as positively influencing fish welfare. An explanation for this difference between the respondent groups might be that the rigorous siting governance system restricts the number of fish farms and thus the spread of diseases, restrictions which fish health personnel appreciate. Another explanation could be that fish health professionals as a group is not strongly involved in farm siting compared to issues such as lice and PD where they are much involved. Some fish health personnel asked for an overall plan for positioning and operation of the fish farms that can minimize the spread of diseases and parasites, instead of a historically developed patchwork of locations.

Many fish welfare issues can be solved by optimizing the site structure in larger regional areas. Optimal siting and relocation of fish farms is a very complex issue that requires advanced knowledge and modelling, and cooperation with regulators and stakeholders [36–39]. Nevertheless, fish farms are often sited on the basis of relatively brief, simple, and traditional methods of environmental monitoring [4,55]. Sometimes minor adjustments within the site can improve the conditions quite significantly [40]. Today, such changes require new documentation and applications to the regulators.

Ideally, one should start with blank sheets and draw up a new overall plan based on new knowledge, hydrographic models, and more advanced decision-support systems [36]. However, as was commented in the interviews, resources and profit depends on the existing fish farm sites, and potential relocation of sites. Moreover, the complexity and resources needed to map knowledge and resolve conflicting interests (fisheries, spawning grounds, shrimp fields, ship traffic, tourism, municipal land and sea use plans, etc.), in order to arrive at an optimal site plan would be demanding. In the end, this complexity may prevent sufficient improvements in locality structure and give continued negative effects for almost all interests involved.

7. Improving fish welfare governance

Aquaculture governance has been described as being akin to a the so-called "wicked problem" [14] in the sense that uncertainty, lack of knowledge and dynamic problems make it difficult to find good and permanent solutions. This exploration of how the three governance conflicts influence fish welfare have, however, in some ways come to the opposite conclusion. There seems to be consensus on several solutions that can improve animal welfare regarding salmon lice, PD and siting. What is lacking is the will to accept the short-term costs for the sake of the long-term benefits – and an agreement of who is to pick up the bill. This may be explained by the fact that all three conflict cases have elements of the tragedy of the commons, in that what is best for the single farmer or company in the short term, in many cases, is contrary to the common good and long-term benefits [13]. Both the salmon lice and PD conflicts are heavily influenced by external factors, and the majority of the respondents rate the collaboration between regulators in these cases as neutral or poor. The siting collaboration, on the contrary, is rated as good, perhaps because this topic in the survey did not focus on conflicts like spreading disease to neighbouring farms.

All of the conflict cases show that optimal governance is hampered by historical factors and that the industry has reached a kind of Pareto efficiency, which makes it difficult to implement the necessary changes without making some companies worse off, at least in the short-term. Ideally, siting, salmon lice treatment, and PD management should have been carried out on the basis of a complete analysis of site conditions and with a view to minimising spread of pathogens between farms. Starting with a blank sheet would have enabled farm sites to be located in clusters with "firebreaks" [56]. Respondents in all professional groups advocated that sea transfer schedules should be planned in such a way as to avoid that newly transferred fish are downstream of farms where there are large fish, which can be heavily infected with salmon lice, PD and other infectious pathogens. The farmers know that what they do affects the downstream farms, and that they in turn are affected by upstream farms [56,57]. Optimizing the siting structure, as well as scheduling transfers and delousing operations in accordance with each other's, should therefore be in everybody's long-term interest. But as one fish farm manager expressed it in a recent opinion piece [58], "*We all have the same goal, but different thoughts and ideas on how to get there*".

Although improved fish welfare is the reason why many study participants have advocated for a more flexible salmon lice limit, they tended to consider fish welfare at their own sites, and not on other farms. Fish farmers have mentioned how they acquire infestations of adult salmon lice on their fish when upstream farms have deloused, which counteracts their own efforts to combat salmon lice. This was echoed in the survey and interviews about the PD conflict, and many requested that PD should be combated. According to economic theory, effluent fees for pollution (here for instance salmon lice or PD viruses) could be a mechanism for controlling the number of negative externalities that any one producer can inflict on others and the environment [59]. Another potential tool for the regulators here would be to develop a system whereby only fish farms owned by the same company can heavily influence each other, so that the externalities the farms create remain within the same company. To create areas or neighbourhoods that are dominated by one company would require large-scale redistribution of sites but could have the advantage of giving more control to the fish farmers to reduce the spread of pathogens and parasites. Snorkel sea cages have for instance been shown to decrease infestation by 75%, and to reduce the number of delousing operations during a production cycle significantly [60]. But they are laborious to delouse and are therefore still only used by a few committed farmers. However, in case of all farms within an area being snorkel sea cages, the cumulative decrease in infection may reduce infection pressure to an extent that delousing becomes a rare event. Another alternative is to break the connectivity between farms by having fewer, but larger farms as suggested in the Regional coast plan for Sunnhordaland and Ytre Hardanger [61], and more recently in a recommendation from the Institute of Marine Research to the Ministry of Trade, Industry and Fisheries [62]. But although longer distances between farms decreases the likelihood of pathogens spreading between farms, the larger farm size means that the potential consequence of an outbreak for a single farm increase. Similarly, as pointed out in the opinion piece by Ref. [58], from a business perspective it makes sense to have farms spread out in different parts of Norway in order to limit overall risk within a company. Further, when disaster strikes in an area, e.g. harmful algae blooms of large disease outbreaks, it may be beneficial to have the resources of several companies to draw upon in order to being able to handle the situation. At stake here are minimising the likelihood of fish being infected by pathogens from other farms on one hand, vs. minimising the consequence of large-scale outbreaks on the other. These conflicting mechanisms should be considered in management and regulation of aquaculture sites and licenses.

This study concludes that the main problem is not disagreement between actors about what is best for fish welfare, but the enormous complexity of steering a network of farms that influence each other, owned by companies with different strategies, resources and short-term goals towards a long-term optimum. Creating regulations for limiting the cost for fish farming companies that take on additional burdens for the common good, while taxing companies that add negative externalities, with the result that they must face the true cost of their actions, could nudge the industry towards low-cost ways of reducing pathogenic emissions and thus increase fish welfare. It is also easier to absorb the costs of improving long-term welfare if one knows that their effects will not be quashed by neighbouring farms.

Finally, there is also the moral question of how one weighs animal suffering against economic costs and other interests and values. The current study indicates that fish welfare is currently not always prioritised, and that there is concern regarding fish welfare among the respondents throughout the sector, from the industry itself to the regulators. To utilise this common concern to improve governance towards good fish welfare should remain a top priority.

Author statement

All authors are employees at independent research institutes or universities and have no affiliations with or involvement in any organization or entity with any financial or competing interests in the subject matter or materials discussed in this manuscript.

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