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Animal welfare in fish hatcheries

SMÅFISKVEL

Veterinærinstituttet
Norwegian Veterinary Institute

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Summary

Compared to farmed fish at sea, reported mortality from the freshwater production phase of salmon and rainbow trout has received less attention in Norway. By examining mortality data during smolt production, we have assessed its suitability as a welfare indicator. Growth and development in the freshwater phase may influence performance post sea-transfer, as shown in a report from the Norwegian Food Safety Authority (NFSA) in 2014 where poor smolt quality was described as one of the main causes of mortality at sea. As the freshwater phase provides a basis for the health status and further growth at sea, the quality of fry and smolts is very important. Furthermore, the Animal Welfare Act emphasizes that animals have an intrinsic value regardless of their commercial value.

The NFSA receives monthly mortality reports from hatcheries. This project is partly based on these registrations. In addition, the hatcheries were asked to complete a survey in an attempt to identify operative conditions, attitudes towards fish welfare and the use of welfare indicators. The results were used to identify conditions that may be linked to mortality or poor welfare, as well as potential success factors. Production type, biosecurity, water quality, welfare and causes of mortality were among the topics of the survey.

The reports from hatcheries to the NFSA include the number of fish in each tank, their average weight and mortality counts for the previous month. Data from 2011 to 2018 were included in the project. In our analyses, the fish are divided into seven weight categories in order to illuminate potential differences in mortality between the groups. Not unexpectedly, the category with the highest mortality was fish under 3 grams. When comparing the time periods, there is a tendency towards significantly higher mortality post 2014. However, the data quality is lower than we had hoped for. In order to carry out good analyses, improved quality of data and reports is essential. Suggestions on how reports can be improved upon are summarized in the conclusions.

The survey respondents were predominantly salmon producers, and most of them rear smolt from fertilized eggs in an in-house hatchery unit. Flow-through system hatcheries, RAS (recirculating aquaculture systems) hatcheries and those using a combination of both technologies participated in the survey. The most commonly used welfare parameters in hatcheries comprise mortality, wounds, fin damage and shortening of the operculum. Failure of technical equipment was reported to account for a large proportion of welfare challenges.

Disease control is another important welfare measure. Questions related to hygienic conditions were therefore included in the survey. Before RAS hatcheries became more common, “all-in-all-out” was an important hygienic measure. However, it is a major disadvantage to disassemble a biofilter between fry batches as a mature biofilter has the highest cleansing capacity. Keeping the biofilm between fry batches may however increase the risk of transmitting disease, even though we could not detect this in the present study.

The number of smolts a hatchery can produce varies greatly. There is also a notable difference in smolt yield, possibly due to different routines for destruction of fry. In this study, no differences were found when comparing mortality and size of the production permit.

The impact of fish density on welfare and health is closely linked to water quality and exchange rate in the tank. It is therefore the hatchery’s responsibility to set the density limits. The recommended range for water temperature depends on the developmental stage of the fish. Not all hatcheries in this study operate within the recommended limits. Hatcheries unable to decrease the temperature may face problems with high temperatures during the summer months.

Situations involving handling are stressful for the fish. Nevertheless, handling and grading can be beneficial welfare measures because even-sized fish groups show less aggressive behaviour towards e.g. weaker individuals. In this study, no difference was found when comparing hatcheries where fish are graded a few times and where they are graded multiple times.

Proper smoltification is important to get a good start in life at sea. Smoltification is also a vulnerable phase for the fish as they undergo major physiological changes. Therefore, the survey included questions about which methods are used to induce smoltification.

A study on fish welfare must include disease. Few of the hatcheries in this survey report particular problems with disease. Among the mentioned diseases, HSS (haemorrhagic smolt syndrome), wounds, IPN (infectious pancreatic necrosis), pox virus infection and HSMI (heart and skeletal muscle inflammation) are the most common. Mortality values in hatcheries that report problems with HSS are not higher compared to those who do not consider it a problem.

Fish are vaccinated during the freshwater phase to protect them from severe infections during the sea phase. At the same time as vaccination, fish with external flaws will be removed from production. Deformities, shortening of the operculum and undersized fish were reported as the most common reasons for removal and destruction.

In the reports to the NFSA the cause of mortality is not required. Therefore, we cannot distinguish between fish that have perished, scheduled destruction of fish and destruction for welfare reasons. Almost 90% of the hatcheries register cause of death on their own initiative.

Apart from significantly higher mortality rates in the weight category below 3 grams, and an increase in total monthly mortality in the period after 2014, no significant differences were found between different operative models and other conditions in the hatcheries. It is important that the categories of registrations reported to the NFSA are revised, so that it is possible to find both success factors and conditions that increase the risk of poor animal welfare in smolt production.

FIG 1. Example of a new hatchery with large units.

Background

The attitude towards animals and how we treat them varies between different cultures, including their uses and emotional value to us humans, but also the level of knowledge we have concerning each species and their needs. In countries such as Norway, where fishing has been an important livelihood, fish were traditionally not considered capable of sensing fear and pain. Nor was it recognised that removal from water is a significant stressor for our common fish species. The limit for what is acceptable or 'good animal welfare' will therefore change as we gain more knowledge, which in turn will influence old traditions. As knowledge levels are never uniform, it is important to have official regulations on how to treat animals.

Rules for treatment of animals in Norway have changed along with how we view animals. As early as 1842 the Penal Code included a ban on animal abuse. In 1929, exsanguination without sedation was banned. The first Norwegian independent law on animal protection was introduced in 1935, which prohibited the neglect of animals. In 1974, another law on animal protection, also including fish, aimed towards protecting animals against unnecessary pain. Our current law, the Animal Welfare Act, came into force January 1st 2010 and stated that animals shall be treated well and protected against unnecessary strain. It is also specified that animals have an intrinsic value regardless of their use to humans, and that fish are equal to other farm animals. The EU has not extensively regulated animal welfare but its member states are bound by the European Council's recommendations in addition to their national regulations. The EU adopted a new animal health law in 2016, due to be implemented in 2021, but this does not specifically include animal welfare. Preventing diseases from spreading is likewise a very important welfare measure.

Regulations often provide details and elaborate on the intentions of legislation. The Aquaculture Operating Regulation (Akvakulturdriftsforskriften) is particularly important in this respect. Amongst others it includes a provision on the information aquaculture hatcheries must report to the authorities, and in § 58 it states that they shall submit monthly reports to the Norwegian Food Safety Authority concerning the following information for every production unit currently in use containing first feed fry or older fish: number of fish, average weight and mortality.

FIG 2. Fry towards the end of the first feed period.

In addition, there is a general obligation to notify the authorities as stated in § 13, i.e. the NFSA must be notified immediately in case of:

a) unexplained increased mortality
b) reason to suspect a list 1, 2 or 3 disease, or
c) other conditions that have caused severe welfare issues for the fish, including disease, injury or technical failure

In 2018, the NFSA received 58 reports of welfare related incidents in hatcheries. Two of these were related to vaccination, one to counting, one to pumping and one to natural forces. The remaining reports were divided evenly between “unexplained mortality” and “other”. It does not say what is included in “other”, or whether the cause of mortality was identified at a later time. Comparatively, there were 1036 reports of welfare incidents at sea sites in 2018, clearly dominated by non-medicinal delousing, with handling procedures counting for 61 % of the incidents. Mortality in sea farms has received a lot of attention for several years without resulting in the desired reduction of mortality. Persistent, high mortality is a result of exposure to conditions that are not compatible with good animal welfare. Even though a large portion of the mortality is probably related to non-medicinal delousing, there are clear geographical variations and differences between farm sites/companies, which may indicate that a significant reduction in mortality is possible.

It is important to bear in mind that mortality during the sea phase may also be attributed to conditions in the hatchery. In a report from the NFSA (2014) (1) it was concluded that “smolt quality” was one of the main causes of mortality at sea. They did not elaborate on what is included in this term. Naturally, smolt producers put a lot of effort into producing “good” smolt, yet there has been less focus and little public knowledge on operative management and welfare in hatcheries. Since every fish has the same intrinsic value regardless of whether their financial value increases during production or not, there is good cause to investigate why approximately 25 % of hatched salmon fry never reach the sea phase. In this project we wanted to find out how high the mortality in hatcheries truly is and whether the mortality values submitted to the NFSA every month can be used as a welfare indicator. The Norwegian Animal Protection Alliance (Dyrevernalliansen) has asked the Norwegian Veterinary Institute to suggest investigative aspects that may reveal the most significant risks in smolt production. Could hatcheries possibly do a better job in terms of welfare so that the smolt quality improves? If successful, the fish may become more robust and better prepared for life at sea.

Since there are no previous attempts to use mortality reported to the NFSA in further analyses, the number of fish that die or are destroyed during a production phase is not documented in the same way for hatcheries as in sea sites. We also have limited knowledge on causal relationships concerning the mortality.

The level of knowledge on production of salmon and rainbow trout from roe to sea-transfer has increased enormously. Technology has also seen huge advancements, with a very high degree of automation. In less than 40 years, feed development, breeding, use of lighting and temperature has reduced the production time from two-three years to around nine months. Farm sites and units have greatly increased in size. The capacity of each farm site is sometimes exceeded due to the willingness of companies to constantly push boundaries. Because salmon and rainbow trout are naturally robust, this strategy can succeed for a long time, until something causes a delay in one unit and a falling domino effect is created. In some hatcheries there is no reserve capacity, so if something goes slightly wrong it may quickly escalate, for instance if there is a delay in sea-transfer of smolts.

FIG 3. In Norway there is plenty of surface water but is the quality good?

In Norway, there is plenty of surface water and yet access to freshwater is a limiting factor in smolt production. Available volume as well as quality varies with the type of bedrock in drainage basins. Precipitation will also affect the water quality since it may carry pollutants across very long distances. In storms with strong winds, sea salt may influence freshwater sources. In addition, there is a restriction on water withdrawal in many water sources. For many watercourses this is regulated by the Norwegian Water Resources and Energy Directorate. Examination of the freshwater sources must be performed before planning the farm site, not only considering the amount of water that may be withdrawn throughout the year but also its quality. If the raw water has to be treated in order to give the fish an optimal environment, this should be in place before production begins in order to avoid surprises with poor welfare and death shortly after production has started.

In the autumn of 2013 and spring of 2014, the NFSA conducted an inspection campaign to investigate water quality and water treatment in hatcheries (2). 108 hatcheries were inspected. They found no severe deviations in their routines to secure a good aquatic environment but they did find minor deviations at 61 farm sites. The main deviations were identified relation to risk assessment and systematic measuring of water quality, as well as inadequate disinfection routines for intake water and exceeding recommended values for metabolic waste.

Over time, the fish density may become very high in many hatcheries. There are huge investments behind the farm sites, requiring intensive production. For sea site net pens, § 46 of the Aquaculture Operating Regulation allows a maximum of 25 kg of fish/m^3 but does not specify a limit for tanks on land. Instead, there is a general requirement stating that fish density shall be reasonable and adjusted according to water quality, production type, feeding technology as well as behavioural and physiological needs and health status of the fish. If the water quality is maintained within an optimal range and the fish receive enough feed, then they may tolerate very high densities (3, 4) but in commercial farm sites it may prove difficult to achieve optimal conditions at all times.

Most of the hatcheries being built today are recirculating systems (RAS farms), but in total there are more flow-through systems. Large investments require rapid initiation of production. In addition, the biofilm in the bioreactor, usually called the biofilter, must be stable. The biofilter cleanses the water and must be up and running before fish production starts. However, a functional biofilter may take several weeks to mature. If fish production exceeds the capacity of the biofilter, it causes poor water quality. Suboptimal design of such farms or incorrect usage have also led to mass mortality in the past.

There is no available documentation on whether flow-through and RAS farms differ in terms of mortality and welfare. What we do know is that managing a RAS farm requires great skill. It is our impression that not everyone who runs a RAS-farm has the necessary technical and biological knowledge required. Our experience is also that when something goes wrong, it goes horribly wrong. This was demonstrated in a presentation given by Gjensidige at Tekset 2019, concerning payment of insurance policies. Problems may stem from insufficient knowledge on how to manage the farm site, but also constructional errors.

The mortality values reported to the NFSA do not include cause of death or welfare statements. To investigate this, we sent a Questback survey to all hatcheries reporting to the NFSA, enquiring about management and views on fish welfare and health. The questions were designed to illuminate attitudes and husbandry techniques. Is a particular production type associated with high survival rates? Are results affected by views on fish welfare? We also asked how staff evaluate fish welfare at their farm site.

Objectives of the survey

Main objective:
Describe mortality as a welfare indicator in smolt production.

Subsidiary objectives:

- Obtain an overview of the quality of reported data from hatcheries
- Survey mortality counts and estimate mortality in hatcheries
- Identify production parameters affecting mortality
- Evaluate mortality profiles related to different production parameters to identify when and where the most important health and welfare issues occur during the production cycle in hatcheries
- Obtain an overview of the most appropriate production parameters to follow up when testing welfare improvement measures in hatcheries

Potential uses

The project “Animal welfare in fish hatcheries” (SMÅFISKVEL) highlights good animal welfare and health in smolt production, and how it may be measured. Smolts represent the foundation for the entire salmon production industry. Consequently, it is very important to find appropriate welfare indicators for all phases from roe to slaughter. The project evaluates reported mortality counts, along with a survey to help reveal weaknesses in the reporting regime. The work may lead to better systems for measuring fish welfare in the future. We wish to highlight proper animal welfare and health throughout the entire production cycle. We feel that good welfare in hatcheries will be important in itself, but will also create more robust smolts, capable of handling transport in well-boats and the transition to life at sea.

By identifying perceived risks and success factors in hatcheries, it will be possible to translate experience into knowledge and make it available to other smolt producers. Smolt production is much like a craft where many different factors influence the result, and it is not always easy to see the bigger picture when focusing solely on one’s own production. Comparing experiences may contribute to the dissemination of knowledge and in turn improve animal welfare.

Increased knowledge of everyday life in hatcheries, and identification of situations and types of handling which increase the risk of reduced animal welfare will not only benefit salmon production but also aid the supervisory authorities in making better risk assessments. The knowledge may also be of importance in potential regulatory improvement and administration.

In addition, the project may serve as a foundation for further research, for instance by revealing knowledge gaps or shortcomings. The processes surrounding transfer of smolts to sea are not covered by this project. Further investigations are needed, along with an evaluation of the relationship between the freshwater phase and sea phase in terms of robustness, which is also not covered here. Main conclusions and advice derived from the project are summarised in a separate chapter.

Materials and methods

The project consisted of two parts:

1. Collection and analysis of monthly mortality data from hatcheries.
2. A survey covering different hatchery conditions

1. Collection and analysis of monthly mortality data from hatcheries.

All hatcheries must submit monthly mortality reports to the Norwegian Food Safety Authority, as stated under § 58 of the Aquaculture Operating Regulations. Reports must represent production on the level of each unit. Because reports are submitted monthly and do not follow specific fish groups, mortality is listed per month, not per year.

The NFSA has allowed us insight into monthly reported data for the period 1.10.2010-13.5.2019.

Every report contains the name of the farm, farm site ID, unit number (tank, cage or similar), stock (number of fish), average weight and mortality. There is a monthly report per unit.

A significant number of reports stated stock as zero. After conferring with Akvagroup and the database Havbruksdata, we were informed that this was an error and we were instructed to disregard the reports in question. A number of reports appeared more than once, and were subsequently reduced to a single report. The analyses included reports for the following species: "Salmon", "Trout (farmed)" and "Rainbow trout (farmed)".

All analyses in this document are based on data from 2011-2018, in order to only include data from whole years. For the period 2011-2018 there were a total of 471.533 reports. Deletion of duplicates reduced the number to 463.922. After deleting reports stating stock as zero, the final count was 317.204 reports (table 1).

In total, 190 individual farm sites submitted reports, as shown in table 1.

TABLE 1. Overview of the number of farm sites reporting mortality numbers per year. The table also shows the number of reports stating stock as >0, as well as the percentage of reports stating stock as zero.

Year	Number of farm sites	Percentage of reports stating stock as = 0	Number of reports stating stock as >0
2011	134	37.7	32.492
2012	146	36.6	36.707
2013	146	38.6	40.676
2014	139	38.1	42.011
2015	141	31.8	41.993
2016	146	20.1	39.599
2017	153	20.3	42.377
2018	151	25.0	41.349
Total for 2011-2018	190	-	317.204

Of the 317.204 reports, 162 gave average weight as = 0. These were excluded from further analyses. In addition, some reports stated very small numbers of fish held. We chose to disregard all reports with stock of 10 or less (604 reports). That left 316.438 reports to form the basis of further analyses.

The average stock for each farm site varied from 66.000 to 14.794.422. Figure 4 shows the average stock per month for each farm site, divided into weight categories.

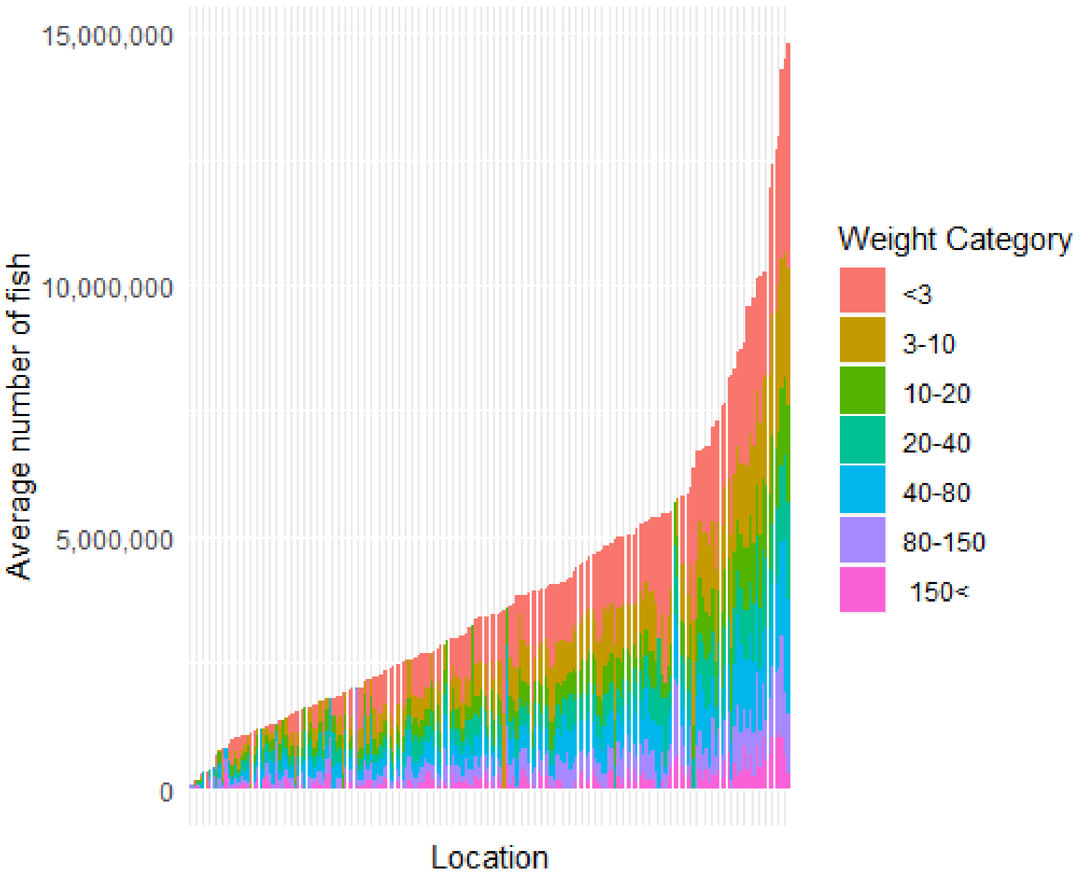


FIG 4. Average monthly stock per farm site for the period 2011-2018. The colours indicate the number of fish in each weight category as stated by the legend.

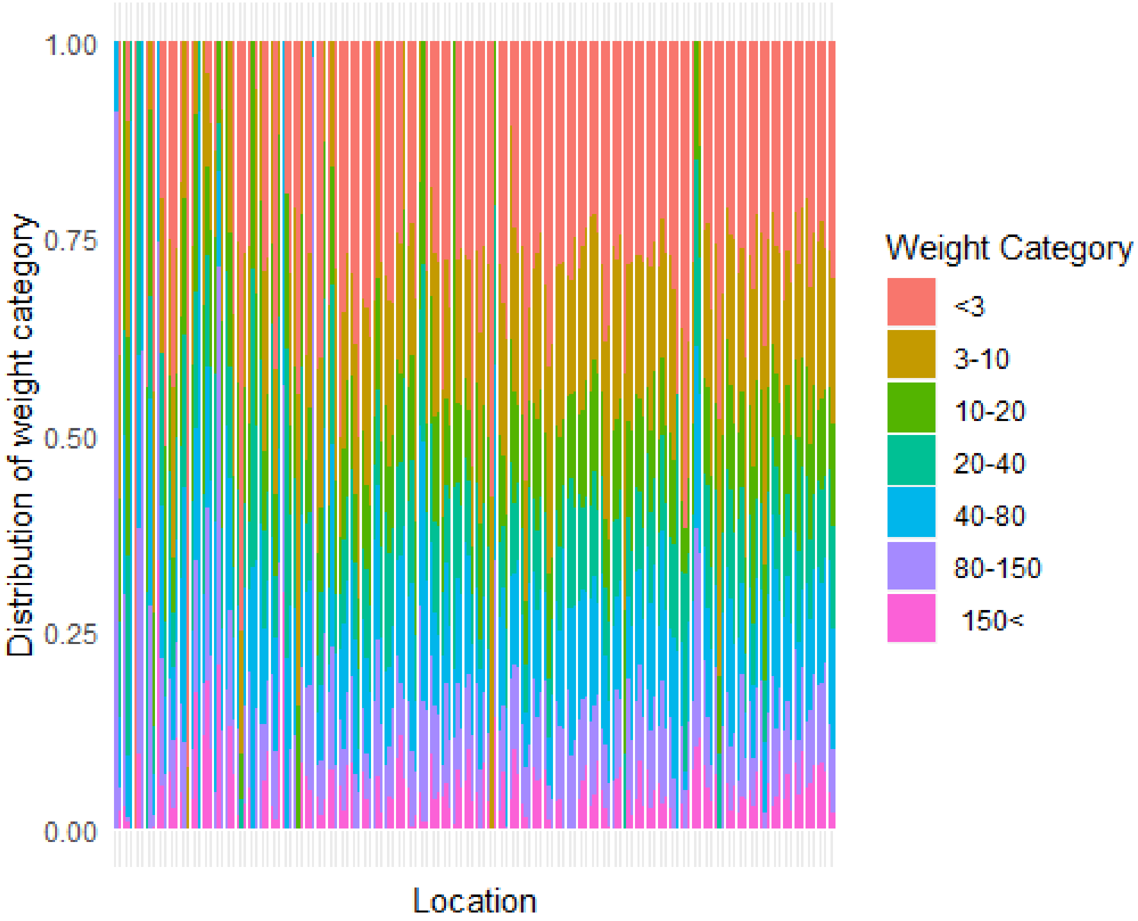


FIG 5. The figure shows the distribution of different weight categories in each hatchery. The columns add up to 100%.

Since the annual number of fish introduced into farm sites and the number of fish distributed as smolt are unknown, it is not possible to calculate the annual mortality. Instead, we calculated the number of dead per month along with the total number of dead fish. In order to evaluate mortality in different weight categories we used the following grouping: <3g, 3-10g, 10-20g, 20-40g, 40-80g, 80-150g and >150g. Figure 5 shows the distribution of fish in the different weight categories for each farm site. It is apparent that most hatcheries hold fish of all weight categories and that the <3g is the largest, counting for around 25 % in each hatchery. For each farm site and month, we summed up the reported stock and mortality numbers for the given weight categories. The number of dead fish was then calculated:
Number of dead / (stock + number of dead)
This resulted in a total of 36.745 mortality calculations with different combinations of date, weight category and farm site.

TABLE 2. The number of calculated mortality in each weight category.

Year	<3g	3-10g	10-20g	20-40g	40-80g	80-150g	>150g
2011	417	406	451	735	966	539	99
2012	465	470	526	749	1.058	694	194
2013	540	541	561	810	1.184	778	229
2014	530	501	532	786	1.155	908	300
2015	541	508	528	738	1.140	955	341
2016	559	515	524	733	1.104	1022	388
2017	637	550	573	725	1.055	977	444
2018	651	546	579	769	1.115	941	463
Total	4.340	4.037	4.274	6.045	8.777	6.814	2.458

Statistical analyses on mortality were performed to identity potential statistically significant differences between weight categories and years. The analysis is a linear mixed effect model, with farm site as random effect and year and weight category as fixed effect. The presumptions behind this analysis are a little challenging for these data, thus the results are only presented graphically to demonstrate general tendencies.

2. Questionnaire concerning different conditions in hatcheries

A web-based survey was prepared in order to collect information on conditions that may be relevant to mortality and welfare in hatcheries. The survey posed questions on the following:

- Production; type, age of hatchery, species, type of fish produced, number, water source etc.
- Conditions concerning biosecurity; use and disinfection of seawater, cleaning and washing of tanks, disinfection of eggs, handling dead fish.
- Water parameters; what is measured, limits for oxygen values, CO_2 and others, problems with water parameters.
- Causes of death; which diseases are the most important, which age groups are affected, which production phases are affected, causes of mortality, registering mortality.
- Welfare; use of parameters to measure welfare, problems with poor welfare, the staff's focus on welfare.

Three-four smolt producers helped develop the survey. The survey was then reviewed by two smolt producers to ensure its practicality. Surveys were distributed by email to 125 possible respondents who have submitted mortality numbers according to § 58 of the Aquaculture Operating Regulation. Two gift certificates were randomly awarded to increase the response. Those who had not replied by one week before the deadline received a reminder by email. After the deadline expired we called them to encourage their participation.

In order to investigate whether any of the addressed production parameters influence mortality, we carried out separate analyses for selected potential risk factors. The model displays monthly mortality as the response variable, farm sites are included as random effect and year and weight category are forcibly included. Further information on the statistical analyses may be given upon request. The following potential risk factors were included in the model:

- Production type; Flow-through or recirculation system
- Water source: River, lake or other
- Amount of water: Sufficient amount of freshwater or not
- Whether the hatchery has experienced several episodes of increased mortality due to oxygen failure or not
- Cleaning: If equipment and tanks are always disinfected following cleaning or not
- If roe is disinfected before it is introduced into the farm site or not
- How many times the fish are graded during their time in the hatchery
- Whether HSS is stated as an important cause of death or not

Results and discussion

Analysis of data reported from hatcheries to the Norwegian Food Safety Authority

Figure 6 shows the total number of dead fish per weight category per year, and the data behind it is listed in table 3.

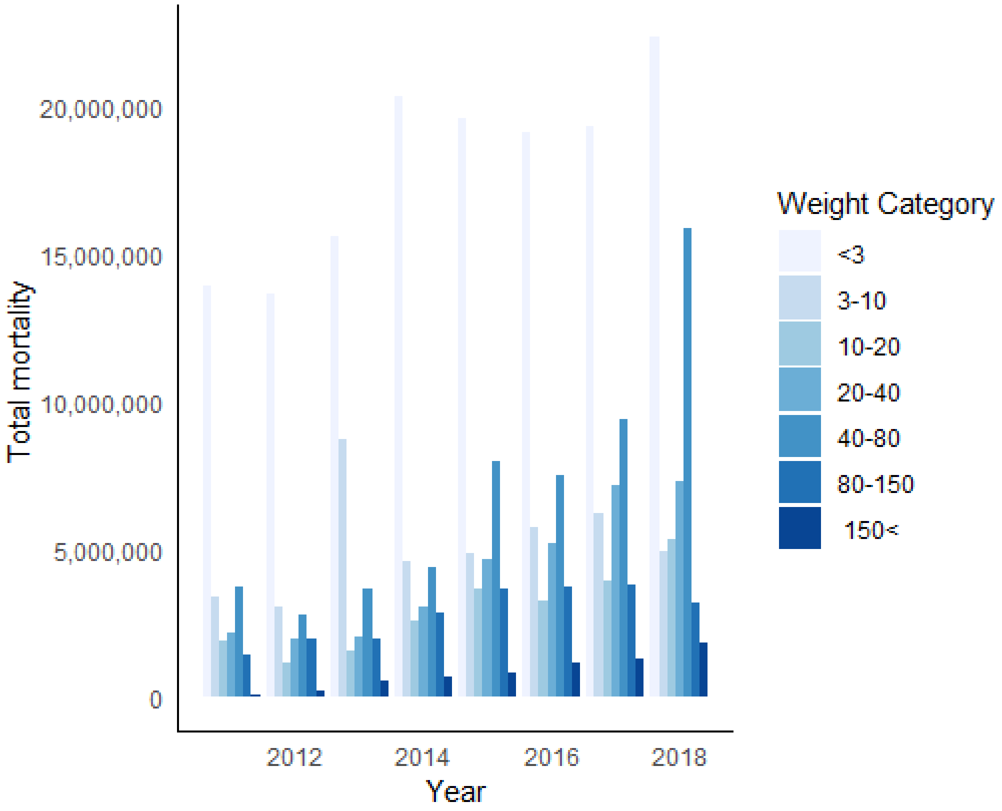


FIG 6. Total mortality in all hatchery sites broken down by year and weight category.

The figure and table demonstrate significant differences in mortality for each weight category, as well as a steady increase in mortality from 2012 to 2018. The total mortality has increased from 24.9 million in 2012 to 61.0 million in 2018, with notable contributions from the weight category 40-80 grams which saw a fivefold increase in the same time period. As we do not know the total number of fish introduced or produced, we cannot say if there is an increase percentage wise. Fish under 3 grams represent 44 % of the total mortality.

TABLE 3. Total mortality per year for each weight category.

Year	**Weight category**							
	<3	**3-10**	**10-20**	**20-40**	**40-80**	**80-150**	**150<**	**Total**
2011	13.964.136	3.385.847	1.894.978	2.161.510	3.753.885	1.477.321	107.907	26.745.584
2012	13.682.765	3.034.223	1.188.841	1.976.757	2.816.347	1.983.004	232.789	24.914.726
2013	15.653.779	8.716.290	1.551.499	2.067.445	3.646.373	1.986.660	599.203	34.221.249
2014	20.355.566	4.634.286	2.611.529	3.035.275	4.396.157	2.839.053	710.325	38.582.191
2015	19.631.153	4.900.349	3.698.784	4.677.776	8.011.775	3.688.541	842.988	45.451.366
2016	19.170.863	5.779.998	3.298.688	5.238.403	7.528.864	3.727.982	1.174.612	45.919.410
2017	19.318.773	6.255.667	3.921.514	7.168.562	9.426.030	3.784.093	1.300.487	51.175.126
2018	22.365.028	4.943.563	5.391.085	7.328.789	15.890.650	3.214.915	1.863.223	60.997.253
Total	**144.142.063**	**41.650.223**	**23.556.918**	**33.654.517**	**55.470.081**	**22.701.569**	**6.831.534**	**328.006.905**

The average proportion of dead fish per month is shown in figure 7 A and B. They illustrate both the average and the median mortality for each weight category per year.

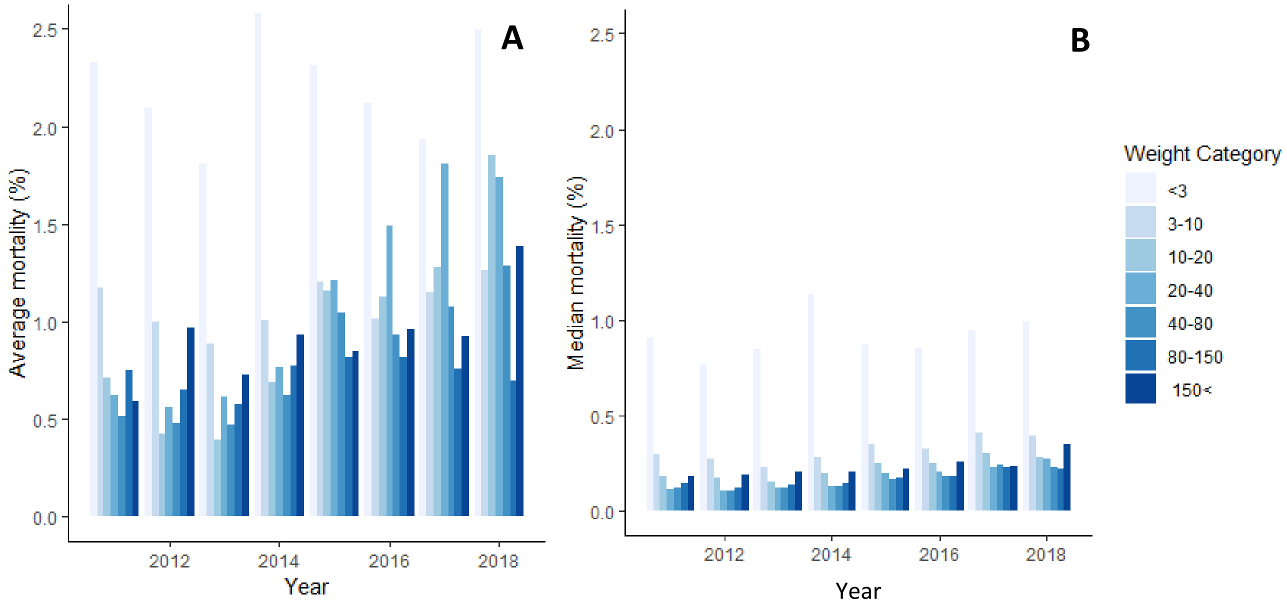


FIG 7. Average mortality (left) for each weight category per month, and median mortality (right) for each weight category per year.

As shown in figure 7, the monthly mortality is much higher in the lowest weight category than in any of the others, every year. In addition, there is an increase in the monthly mortality from 2015 to 2018 while there is only a small increase from 2012 to 2014. This indicates an increase in production over the years, which is supported by statistics from the Norwegian Directorate of Fisheries stating that in 2012, 284 million salmon and rainbow trout <250 grams were transferred to sea sites, and in 2018 324 million.

The mortality varies considerably. Figure 8 shows the estimated mortality for each weight category making allowances for year-to-year variations. The graph illustrates the estimated expected mortality (black dot) for every weight category, as well as the confidence interval (purple bar). The red arrows are used to determine whether the differences between categories are statistically significant at a 5 % significance level (arrows that do not overlap indicate a difference). This means that for the weight category <3 grams the mortality is considerably higher than that of the others, while there seems to be no relevant difference between the remaining categories.

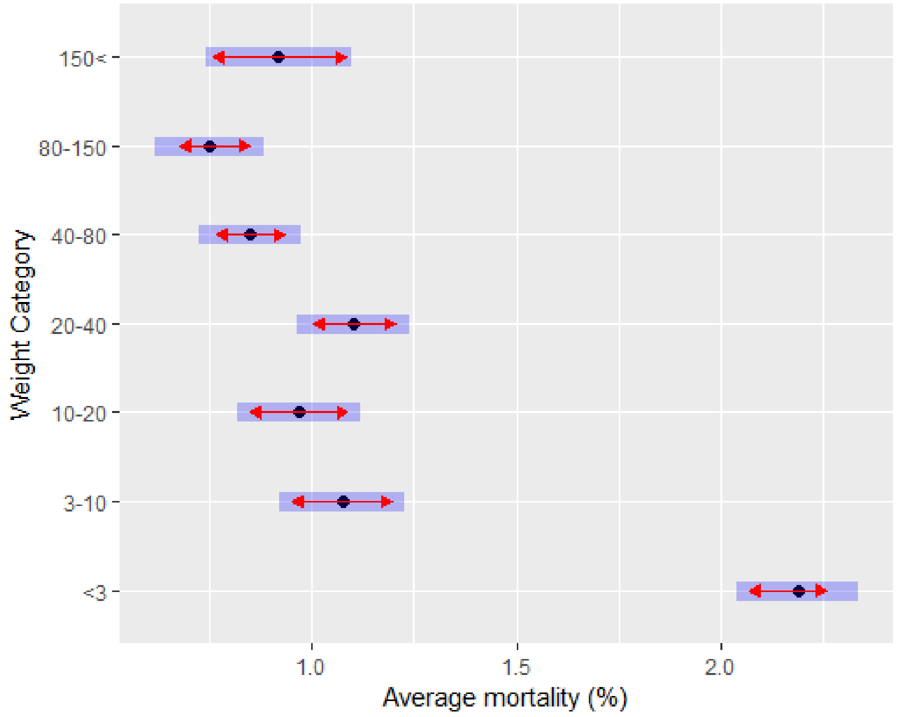


FIG 8. Average monthly mortality for each weight category (black dot). The purple bar shows the confidence interval and the red arrows indicate possible differences between groups.

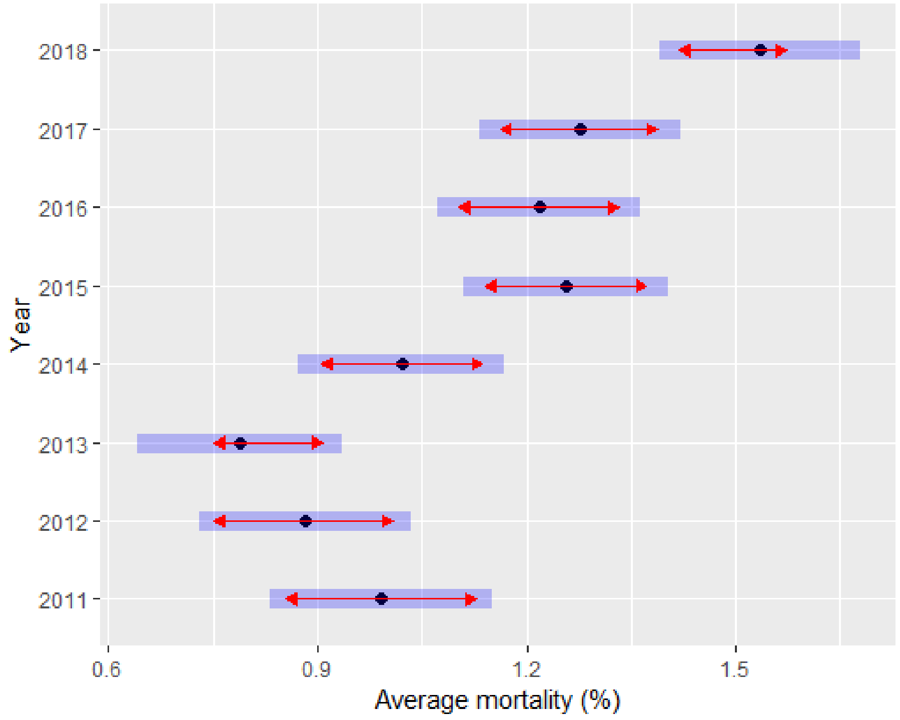


FIG 9. Estimated average monthly mortality for each year (black dot). The purple bar shows the confidence interval and the red arrows indicate possible differences in years.

Figure 9 shows differences based on years. We observed a tendency of considerably increased mortality for the period 2015-2017 compared to 2011-2014. In addition, mortality for 2018 increased even further. We compared the average mortality per month and weight category with the mortality in order to examine whether size of production influences mortality. As seen in figure 10, there is no connection between the size of fish groups and mortality.

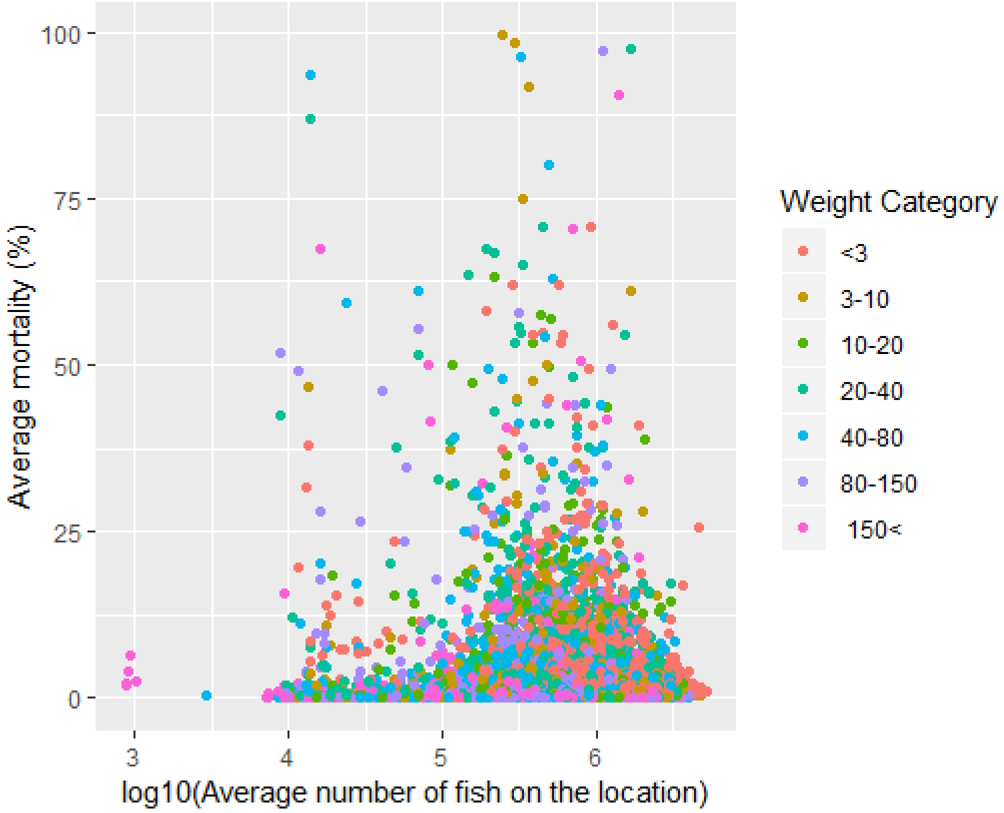


FIG 10. The figure shows the connection between average monthly mortality and the average number of fish per weight category for each hatchery.

It is also interesting to observe the mortality at individual farm sites to see if it is possible to single out hatcheries based on particularly low or high mortality. Figure 11A shows the average monthly mortality per hatchery per year for hatcheries included in the data set. In this figure and the next, only hatcheries holding over 1 million fish are included to avoid the considerable uncertainties arising when the smallest hatcheries are added. To investigate whether any of them have repeatedly higher mortality than others, year after year, we selected 20 hatcheries with the highest mortality for each year, then compared them to see if any recurred over several years. One hatchery was in the “top 20” for six of the eight years, two for five years and five for four years, meaning that a total of eight hatcheries had consistently higher mortality during several years. Figure 11B demonstrates the same, but only for the weight category <3 grams. As the figure shows, the variation between hatcheries is quite significant. For this weight category, two hatcheries among the 20 had the highest mortality for seven out of eight years, four for five years and three for four years. This indicates a considerable potential for reduction of mortality in this weight category. However, we do not know how much of the mortality is due to destruction or selective grading, which may be of particular importance for this weight category.

FIG 11A. Average monthly mortality per year for each hatchery. Each point on the x-axis represents a hatchery. For some, the value exceeds the maximum limit of the y-axis.

FIG 11B. Average monthly mortality per year for each hatchery and the weight category <3 grams. Each point on the x-axis represents a hatchery. For some, the value exceeds the maximum limit of the y-axis.

Discussion concerning mortality data

The reported mortality data from hatcheries presented here has only been occasionally used in presentations and analyses. This has several reasons:

- The quality of the data is not optimal
- It is not possible to follow fish groups throughout a production cycle
- Different hatcheries have different registration practices
- Causes of mortality are not identified

During the present project we found that data is collected without subsequent quality control. As described in materials and methods, many reports state stock as zero, many had duplicates and some gave average weight as zero. Of the 471.533 reports we received, 67 % were suitable for analyses.

Since registrations represent tanks and not fish groups, it is currently not possible to follow different fish groups over time. Practices vary between different hatcheries, but it is common to have frequent transfer of fish between tanks as the fish grow and are graded. That is why tank numbers cannot be used from one month to the next. The average weight may indicate whether tanks hold the same fish group as the previous month, but this is a flawed method. Being able to follow the fish group over time is essential in order to use mortality data to say anything about fish welfare and the effects of different operative management, environment and disease parameters. This will only be possible when inclusion of fish group-ID is made mandatory during reporting mortality data.

Another issue arising from being unable to follow fish groups from month to month, is not being able to calculate the annual cumulative mortality for each fish group. Producers report the stock number per month, but these numbers cannot be summed. For instance, if 8.000 fish are registered in a tank one month, and 7.500 the next, those numbers cannot be added because the 7.500 fish will be counted twice. As long as there is no way to follow fish from month to month, we cannot know whether the 8.000 and 7.500 fish are in fact the same fish. The only thing we can do is to calculate the total number of dead fish, as shown in figure 6 and table 3. However, there is no way to evaluate how much of the total production this accounts for.

It is possible though to calculate the proportion of dead per month. This is done by dividing the number of dead per month with the stock for the same month plus the number of dead. In doing so we assume that the reported stock represents the remaining fish at the time of reporting, that is at the end of the month. There may be different practices for these reports, which makes the calculations uncertain. The regulations should stipulate more clearly the number to be reported.

Another problem is being able to split data. By requiring data reports only on a monthly basis, it is not possible to identify instances of acute mortality. For example, it is not possible to find out whether specific events, such as vaccination, are associated with higher mortality or if there is a difference in mortality when vaccinating fish during smoltification or not. In addition, fish may have been relocated between two reports, which makes it difficult to know exactly which fish are counted. Most producers nowadays use software systems to register stock number and mortality daily, and the data are automatically transferred to Altinn. For this reason, changing the requirement from monthly reports to weekly, or even daily reports will not cause an increased workload for the producers. Altering this, along with requiring fish group ID, will enable the Norwegian Food Safety Authority and other authorities to monitor the mortality in each hatchery over time. One may also imagine a system where producers and the NFSA are automatically notified in case of mortality rates above a defined normal. This way, both will have an opportunity to intervene early. This will require a change in the reporting module of the software system.

Hatcheries are only required to report the number of dead fish, but not the cause of death, unlike sea sites which are required to report the number of dead fish in each of the following categories: dead, rejected at slaughter, escaped and other. Especially at the beginning of production, a lot of fry and abnormal young fish are excluded and destroyed. Therefore, a breakdown of dead fish into categories as for sea sites would provide much better information on what can be described as “unexpected or abnormal” mortality. Again, this information can be collected from the software system directly, as for sea sites.

With these improvements, data may be of use. When information can be used to further explain causes of mortality, and provide a better chance to actually decrease mortality in hatcheries over time, it will increase motivation to report data.

Results from the survey and discussion

Information on respondents and hatcheries

A total of 55 hatcheries submitted a response. Figure 12 shows the geographical distribution of the hatcheries that replied. 76 % stated that the hatchery was built more than 20 years ago, 16 % stated between five and 20 years ago and 7 % stated less than five years ago. Slightly more than half said that the hatchery had undergone alterations or expansions in the past five years.

FIG 12. Geographical distribution of responding hatcheries. Source: Barentswatch.

The hatcheries specify a production licence between 100.000 and 15 million fish, in which 18.5 % stock less than a million, 48.1 % stock one-five million, 25.9 % stock five-ten million and 7.4 % stock 10-15 million fish.

Of the 55 respondents, we were able to relate 53 of them to specific farm sites. Figure 13 shows their distribution in relation to average size. When comparing figures 13 and 4 it is clear that hatcheries in the survey are distributed roughly the same as the complete data set.

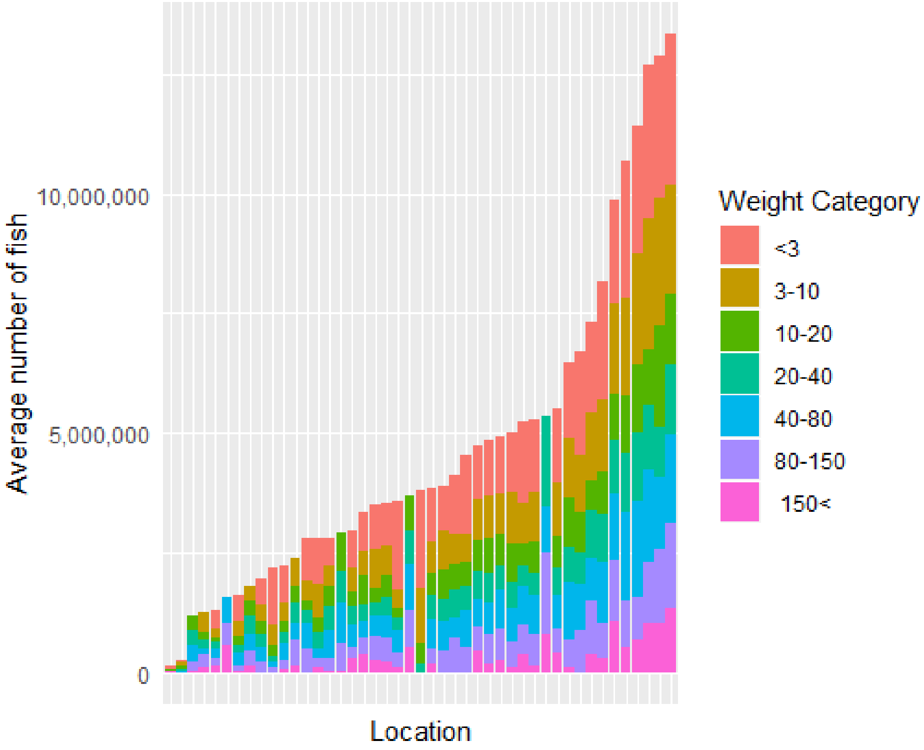


FIG 13. Average monthly stock per hatchery in the period 2011-2018 for the 53 hatcheries included in the survey. The colours indicate the number of fish in each weight category, as listed in the legend.

Comparing figures 14 and 5, the distribution of weight categories appears to be overall the same for all hatcheries.

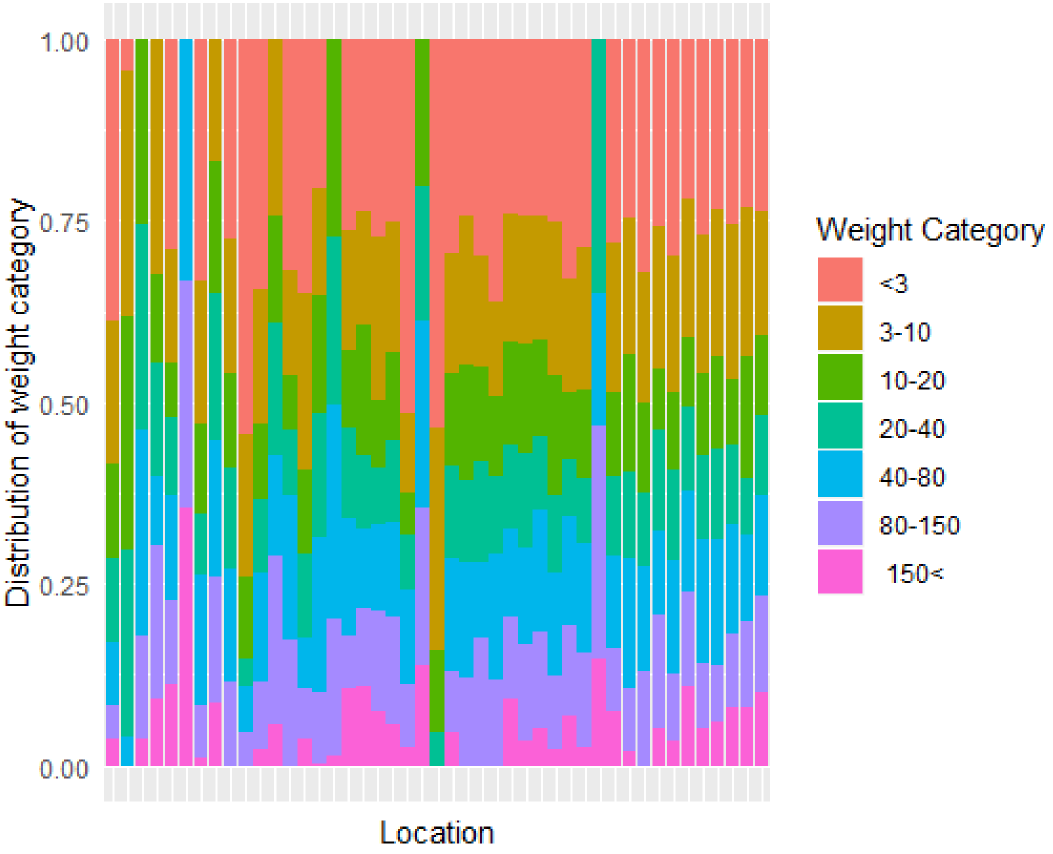
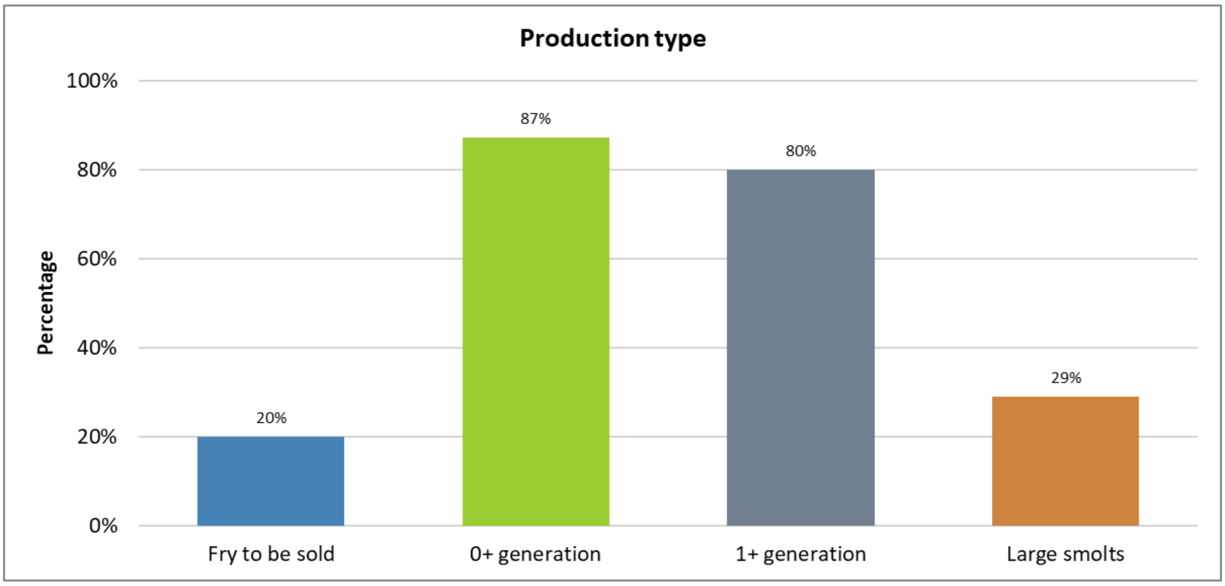


FIG 14. The figure shows how the different weight categories are distributed in each hatchery for the 53 hatcheries included in the survey. The columns add to 100 %.

90 % stated having a flow-through system and 36 % a recirculating system, and 25 % had both. Respondents were mainly operative managers (65.5 %), while the rest were involved in the daily running of farm sites.

General information on operative management
96 % of respondents produce salmon, 13 % produce rainbow trout, with or without salmon, and 13 % produce brown trout.

There has been a significant increase in production of large smolts in recent years. The purpose is to reduce the time at sea before slaughter and in turn reduce the risk of lice infestation and thus the number of delousing treatments. 16 respondents produce large smolts and stated that size varies from 150 to 800 grams at delivery. Half of these hatcheries use RAS technology and all add seawater. Figure 15 shows the distribution of fish species in the participating hatcheries, and table 4 shows detailed information on different methods used in production of large smolts.



15. Distribution of fish species produced in the hatcheries that responded to the survey. (N=55)

TABLE 4. Details on distribution of size and production regime for large smolts.

What is the planned average weight of large smolts at delivery (in grams)?	Is RAS used in this production?	Is sea water used in this production?	If yes, in what ppt?
200-250	Yes	Yes	5
250+	Yes	Yes	15
500	Yes, all units have RAS	Yes, for grow out post smoltification	15-30
170	Yes	Yes	0,5
250-350	No, reuse of water	Yes	Gradual increase to 34
250	Yes	Yes	13-15
250	Yes	Yes	5-15
500-800	No	Yes	About 33
350+	No	Only at the end just before delivery. Otherwise buffering is used.	Buffering 5, 10-15 after smoltification
200-300	Yes	Yes	2
350	No	Yes	14
ca 500	Yes	Yes	About 14
150	No	Yes	16-22
500+	Yes	Yes	15 or more
300-500	Yes	Yes	5-20
All types	No	No/Yes	12

The water source is the most important resource to most hatcheries. In the survey, 70 % state lake as their freshwater source, while 29 % take water from a river and 9 % say they have groundwater or other freshwater sources. Access to water often acts as a limiting factor in production and recirculation has necessarily emerged as a solution to resource scarcity.

In this survey, as many as 91 % of the hatcheries state they have a sufficient amount of freshwater for year-round production, while 9 % say they experience water shortage during certain periods, winter and late summer.

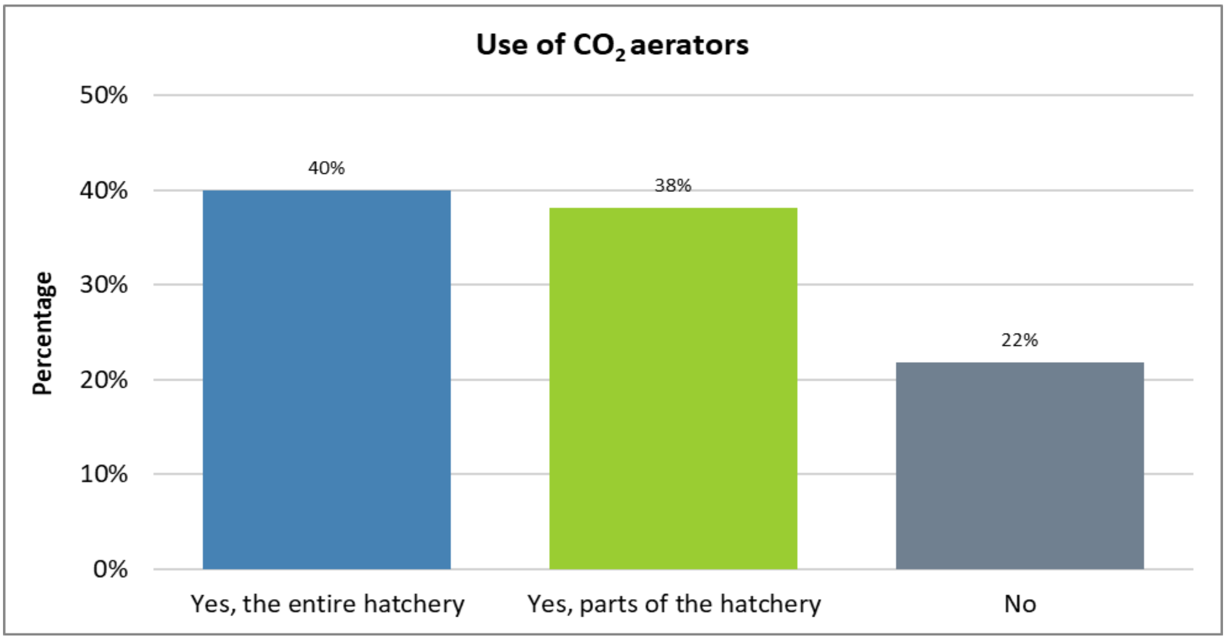


FIG 16. Use of CO_2 aerators. (N=55)

In almost all hatcheries, oxygen is added to the water in order to intensify production and reduce the need for water. However, water exchange is important to remove faecal matter and other waste materials excreted by the fish. The first limiting factor in reducing water consumption is CO_2 excretion by the fish. CO_2 aerators are installed in the tanks to keep CO_2 below recommended limits. In RAS farms aerators are an integral part of the system.

Adding seawater is a common procedure in smolt production, for both flow-through and RAS. Two thirds of hatcheries in the survey add seawater during production. Adding seawater may positively affect the water quality through acting as a buffer, as an extra addition of water where freshwater is scarce and in association with smoltification and haemorrhagic smolt syndrome (HSS), which is a growing concern. Intake of seawater may increase the risk of introducing pathogenic organisms not present in freshwater. All hatcheries using seawater state that the water is disinfected at intake. UV is the most common method but other methods are also implemented. When asked whether they consider the disinfection of seawater as adequate, as many as 83 % answer yes, 8 % say no and 8 % are unsure. Since the disinfection is not always 100 % effective, using seawater poses a biosecurity risk. In RAS technology, addition of salt may be used to avoid this risk, while obtaining the same benefits as with seawater.

Comments concerning operative management

Below is a summary of replies from respondents with supplementary comments regarding management.

«In order to succeed, both technology, management solutions and personnel must work together. It is important that staff in charge of the fish are in fact given enough time to observe, reflect and make good decisions and not spend time on cumbersome tasks and rigging of equipment. »

«Examining the water quality of the water source is not enough, because incidents in the catchment area may create challenges. Power plants, landslides and floods are events that affect water quality but are outside the hatchery's control and may pose major challenges for fish and people. »

«Hatcheries with water intake from rivers know there is a risk of the water intake freezing over during special meteorological conditions. Although such farms have routines in place to avoid these incidents, they are living with the risk. »

«The water source poses a risk of introducing pathogenic organisms into the hatchery. » Only hatcheries using seawater or situated in an area with returning anadromous fish are required to disinfect the intake water.

Almost all technology in hatcheries requires electricity. That is why the Aquaculture Operating Regulation requires alarms and backup systems. However, generators are not always reliable: *«They do not always start quickly enough and sometimes they do not start at all even though there is a power outage. Weekly checks are routine but the extent of these tests is limited and the generator may fail under real conditions. This creates critical situations for the fish. »*
«Many different materials are used in a hatchery, and may be of uncertain quality».

«In order to succeed in smolt production one must spend time with the fish! Plan for effective handling procedures, leading to shorter periods of stress for the fish. For instance, once you have started grading, it is essential to keep going until finished in order to quickly return to normal production. It is important to avoid repeated stress and there must be as much peace and quiet as possible around the tanks. The focus has to be on the fish at all times, and in addition, there must also be extra commitment during critical time periods such as first feeding, vaccination and smoltification. But even a good staff wanting the best for the company, needs follow-up from the administration. »

«Risk assessments are important and require everyone's participation. This is the only way all employees may be familiarised with the hatchery's limitations and solutions. » Risk assessments dictate how procedures and routines should be complied with in order to handle different situations. It is important to specify where the challenges lie, in order to take systematic measures to improve conditions.

«In RAS-farms there must be a balance between fish production and the biofilter. » The biofilm in RAS-farms depends on a steady introduction of waste materials from the fish in order to function well. Running a RAS-farm is knowledge-intensive.

FIG 17. Built-up reservoir next to water intake from river.

Operative management factors and mortality

Figure 18 shows the distribution of average mortality for 2016-2018 in hatcheries using recirculation, flow-through or both. There appears to be no significant difference between production methods. The disparity between hatcheries with the lowest and highest mortality is most prominent in RAS farms, slightly less in combination hatcheries and least in traditional flow-through hatcheries. Some RAS farms appear to have very low mortality, lower than those with flow-through systems, while others experience higher mortality. These variations indicate that some hatcheries have a great potential for improvement, particularly RAS farms. However, one must consider that this is based on the survey and only applies to participating hatcheries.

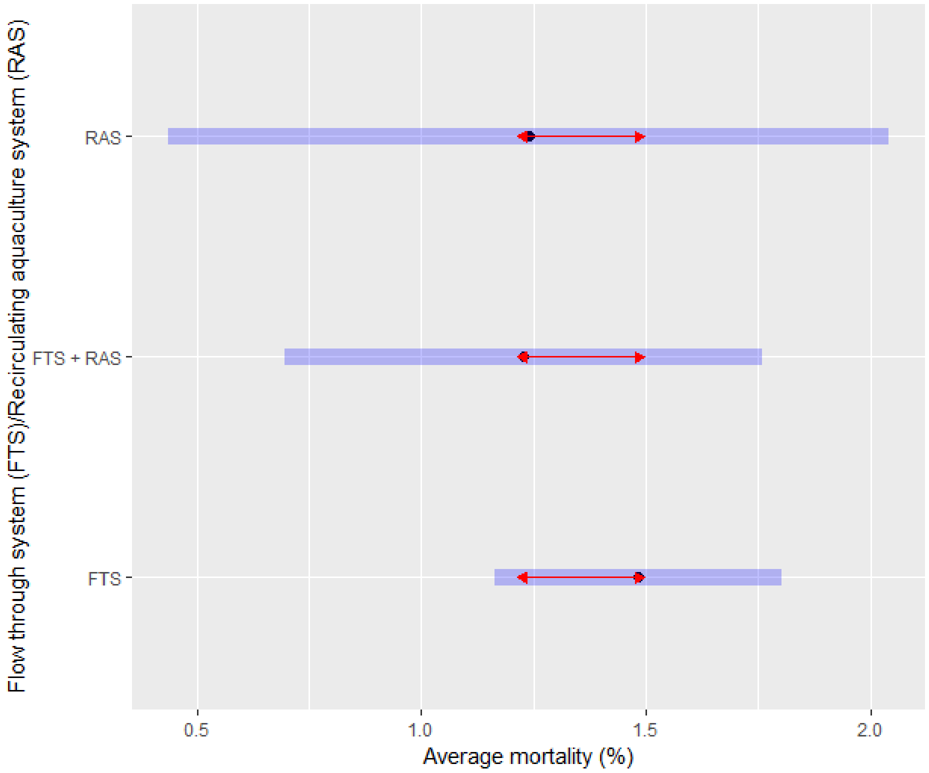


FIG 18. Average monthly mortality for the different production types (black dot) of the 53 participating hatcheries in the survey. The purple bar shows the confidence interval and the red arrows indicate possible differences between groups.

Water source was evaluated as a potential risk factor in terms of mortality. 36 hatcheries stated “lake” as their water source, 13 “river” and four “other”. For the analysis, the categories “other” and “river” were combined in order to examine the relationship between lake water and non-lake water. We observed no significant effect on mortality.

Adequate access to freshwater was also evaluated as a potential risk factor. 47 had sufficient year-round access, while six hatcheries had adequate access for only part of the year. We found no noteworthy effect on mortality related to insufficient access to freshwater during parts of the year.

Water quality

All respondent hatcheries monitor their water quality. In order to correctly measure values, the quality of sensors and their maintenance is important. Location and timing of measuring also influence results but this was not specified in the survey. All the hatcheries measure oxygen daily and almost 75 % declare having a system for continuous surveillance in place. The same applies to temperature. Oxygen and temperature correlate. As the temperature increases, oxygen solubility decreases while the oxygen demand of the fish increases. Oxygen supplementation is a prerequisite in intensive smolt production.

Excessive concentrations of oxygen in the water are unnatural to fish. If the oxygen saturation exceeds 100 %, it will put an increased strain on the fish. Oxygen levels above 110-120 % leads to an increase in free radicals, which has a toxic effect on fish. This forces the fish to activate their detoxifying mechanisms, and is an unnecessary strain, which is why the Norwegian Food Safety Authority recommend oxygen levels of 100 % or less. We inquired about the highest and lowest O_2 values measured in the hatcheries. The replies varied greatly but the majority answered 110-120 % at the highest and over 75 % at the lowest. However, most of the water in the tank may have an oxygen saturation between 80 and 100 %.

FIG 19. Control room in a hatchery.

It is a known fact that CO_2 levels above 15 ppm are unfavourable to salmon and rainbow trout. It is the opinion of some researchers that a CO_2 limit below 10 ppm is advantageous for salmon. Using the CO_2 level of wastewater as a control parameter for water exchange rate at the tank level is not uncommon. About 75 % of the hatcheries measure CO_2 in wastewater at least once a week, while a little over 10 % monitor the CO_2 level continuously. Excessive CO_2 levels affect the acid-base balance in the blood of the fish. Salmon have compensatory mechanisms to maintain stable blood pH, but a result of domestication is that we must provide the animals with optimal living conditions and make compensatory efforts unwarranted. There has been an increase in the prevalence of nephrocalcinosis in recent years. In this respect, excessive CO_2 levels are considered an important risk factor. Nephrocalcinosis has become such a prominent issue that the Norwegian Seafood Research Fund (FHF) plans funding of research to elucidate the causative factors. To our knowledge, the issue is not linked to any particular production method. The survey also requested the highest and lowest CO_2 values. The highest CO_2 level measured varies from 9 ppm in one hatchery to 30 ppm. About half of the hatcheries occasionally detect 20 ppm and higher in their wastewater.

FIG 20. Example of CO_2 measuring.

While salmon are not directly adversely affected by pH fluctuations, they are important due to their effect on other parameters. CO_2 levels affect the water pH. pH affects toxicity of metabolic waste materials and various metals in the water. It is possible to regulate the pH by adding e.g. seawater, bicarbonate, or lime solutions. Silicate is used to detoxify aluminium. 85 % of the respondents measure pH of intake water and slightly fewer measure it in wastewater. The frequency of measuring pH in intake water varies from 44.4 % monitoring continuously to 15 % less than once a week. About 50 % of hatcheries measure pH in wastewater at least weekly.

Less than 10 % of hatcheries measure water exchange at the tank level. Correlation of CO_2 and/or pH levels in water outlet and inlet, is considered a good gauge of flow rate.

Most hatcheries heat water for parts of the production. It has long been known that heating water causes N_2 oversaturation, and all hatcheries aerate the water to prevent oversaturated water reaching the tanks. Many modern hatcheries also pump the water. Leakages in pumping systems causing air influx will also lead to N_2 oversaturation. Severe cases cause gas bubble disease, while persistently slightly elevated N_2 values negatively affects welfare without noticeable symptoms.

FIG 21. Gas bubbles in the eye, caused by N_2 oversaturation.

Additional questions on water quality in RAS farms
For those using recirculation in all or parts of the hatchery, we also asked which parameters they measure in addition to those used in flow-through systems. Here, the most important parameters are alkalinity which provides information on the stability of the water, and total ammonium nitrogen, nitrite and nitrate which represent the bacterial activity of the biofilter. Almost 40 % measure total NH_4^+ and nitrite daily. These are the most critical parameters in terms of toxicity to the fish. Hatcheries with a functioning stable biofilter probably do not see the benefit of measuring parameters more than once a week.

FIG 22. A type of kit to measure ammonium.

TSS – total suspended solids, identifies the amount of suspended particles in the water. This parameter is measured in about 30 % of hatcheries. It is reasonable to presume that muddy water may affect gill health.

Nofima, NTNU, Sintef and others are currently conducting several large research projects aimed at increasing knowledge on the composition of the microbial community of RAS farms and how it affects fish health and welfare. Properly executed, it is possible to achieve a higher water exchange rate in tanks, and as such gain a more stable environment for the fish in RAS farms compared to flow-through systems.

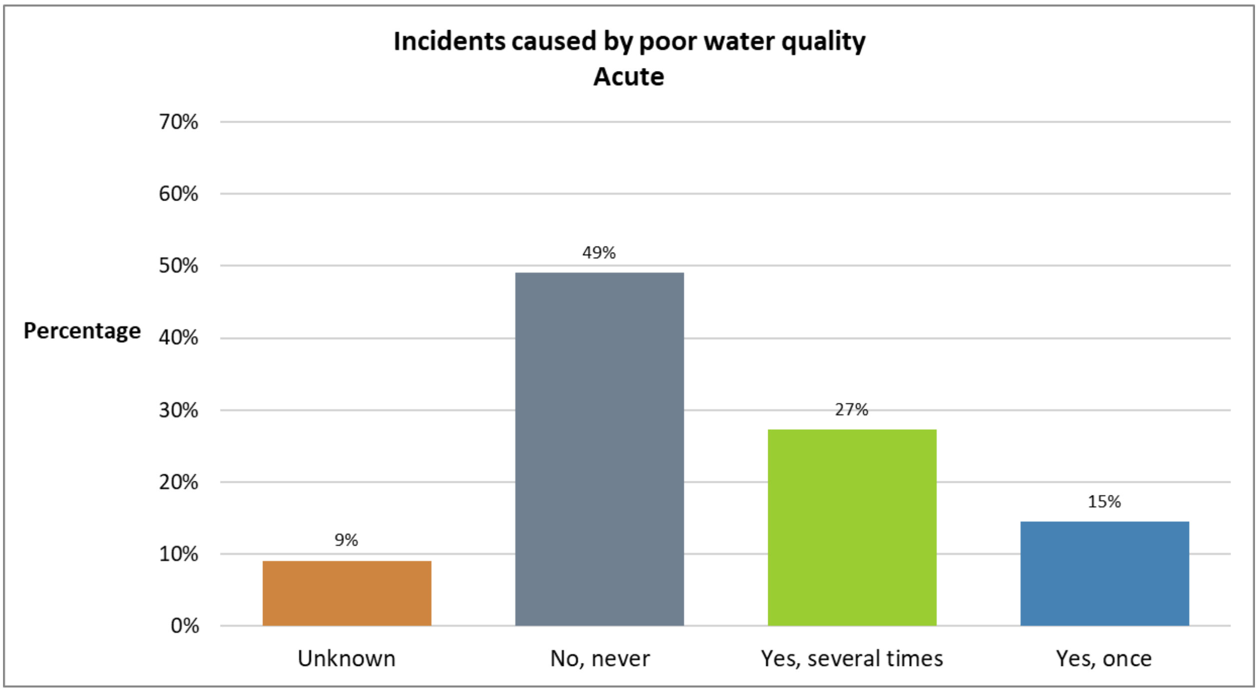


FIG 23. Incidents where poor water quality led to poor welfare. The percentages denote how many of the hatcheries experienced this in the past 3-5 years.

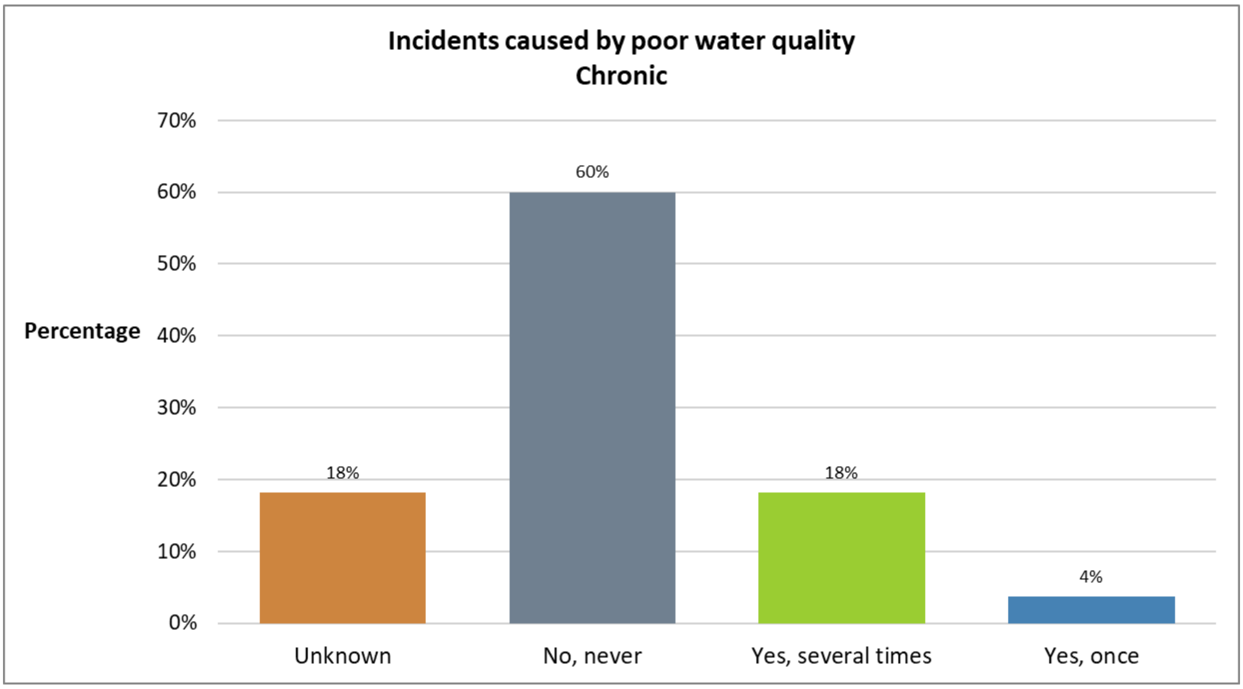


FIG 24. Incidents where persistently poor water quality led to poor welfare. The percentages denote how many of the hatcheries experienced this in the past 3-5 years.

About half of the hatcheries surveyed have experienced poor welfare due to acute cases of substandard water quality. Poor welfare due to long-term issues with water quality occur significantly less frequent. One way to interpret this is that most acute incidents are rectified before they develop into long-term problems.

When asked about the cause of incidents leading to poor welfare, low oxygen level, H_2S, uncontrolled pH, large amounts of rain, flooding, melting snow, landslides, frost, rapid temperature changes, errors in surveillance systems and muddy water were mentioned, among other things.

We investigated whether increased mortality due to oxygen depletion was reflected in mortality reports. Also, if mortality was higher in hatcheries having experienced oxygen depletion several times compared to only once or never. In the model, mortality was the response variable. Oxygen depletion was found to have no significant effect on mortality. This may be interpreted as deficient resolution of data and/or that oxygen deprivation is discovered and rectified before it causes high mortality.

Hatchery employees were also asked if they had experienced mortality caused by one or more water parameters in the past three years. 45 % said they had experienced mortality due to oxygen depletion at least once, 20 % due to insufficient flow-through rate at the tank level and 14 % due to N_2 oversaturation. Employees at RAS farms were also asked if they had observed mortality caused by high total ammonium (15 % said yes, at least once), H_2S (15 % said yes, at least once), nitrite and nitrate. None of the respondents had experienced mortality caused by the last two parameters.

Comments on incidents associated with water quality
The respondents were asked to give examples of incidents associated with water quality. Below is a compilation of their replies.

«*Occasional incidents with poor water quality do not necessarily cause high mortality. It is usually noticeable in the fish before mortality occurs, which provides the opportunity to rectify the problem.* » This illustrates how important it is to observe the fish and their behaviour. However, it is not easily discerned whether increased mortality is caused by the water quality. Some are fortunate enough to have water sources of stable quality throughout the year, while others struggle with surface water of irregular temperature and other variables.

«*Poor flow-through rate in first feed tanks may cause muddy water and increase the risk of gill inflammation*». «*Fungal infections in first feed fry can be challenging.* » Episodes of insufficient flow-through rate do not necessarily cause increased mortality, even though they negatively affect welfare and health. «*Water quality problems are usually associated with technical failure.* » A reminder that good technology is important but also requires close attention. Some technical designs may also be harmful to fish. Unsuitable installations associated with drains/automatic cleaning/dead fish removal may lead to fish being crushed or trapped. «*Capable alarm systems and technicians are determining factors in order to quickly rectify technical failures.* » «*As water temperature increases, so do difficulties with* CO_2. *It is important to have good back-up systems for oxygenation in place. Water intake from rivers may lead to challenges with supercooled water in the winter, avalanches and flooding early in the spring, as well as large fluctuations in temperature from night to day. It is important to know the chemistry of the raw water in order to prepare for episodes of increased toxic aluminium or copper, which can accumulate in the gills.*

There have been cases of very high mortality where H_2S was the suspected causative factor. H_2S is very toxic. Because it is difficult to measure H_2S, the diagnosis is usually made by observing sudden mortality along with black sediment.

Water quality is considered to be a very demanding subject. Biological competence alone is not enough as technical skills are a necessity.

FIG 25. Mass mortality.

General information on welfare
The level of staff consideration for fish welfare is a significant factor in how the fish are treated and handled on a daily basis.

83 % of hatcheries said they have an executive plan to improve welfare. Having such plans would greatly benefit fish welfare if they are used, as it provides an incentive to actively work towards this in daily operations. Staff working with daily operations in all types of hatcheries are required to complete a welfare course, and an encouraging two thirds say that participation in such a course has provided new knowledge or perspective. The remaining third answered that they already knew the curriculum and were using the knowledge. Still, this demonstrates that such courses have a beneficial effect and ensures that everyone has the same level of competence when it comes to fish welfare. These courses

will also provide an opportunity for employees of different companies to discuss fish welfare. The fact that welfare is an important issue is reflected in the survey where 98 % said they have regular meetings to discuss health, welfare and unfortunate incidents.

Measuring welfare

Welfare can be registered and measured both at the group and individual level. Registering welfare indicators on a group level do not involve handling, while for individual fish it usually requires examinations and handling.

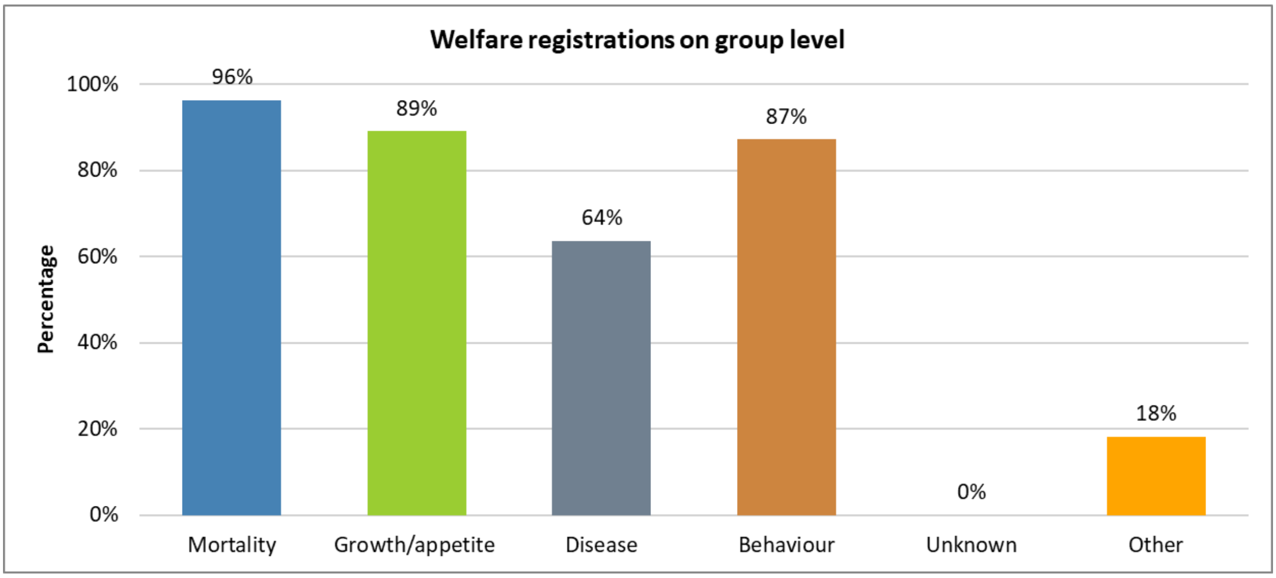


FIG 26. Criteria used to measure welfare in fish groups. (N=55)

Mortality is the most frequently used welfare indicator at the group level. Increased or high mortality indicate poor welfare in the tank or hatchery in question, but it does not necessarily mean that no mortality equals an absence of welfare issues. Daily counting and registration of dead fish provides opportunity to initiate rectifying measures quickly. In addition, retrospective analyses of mortality counts may be used to assess management routines and implement preventative measures going forward.

Sudden changes in appetite may be an early sign that something is wrong, and may serve as an important indicator of reduced welfare. How long it takes before the fish start to eat again following handling and other stressful situations such as vaccination may indicate how well the fish tolerated the procedure. Appetite is, among other things, dependent on temperature and lighting conditions, so changes in appetite are not necessarily connected to poor welfare. Growth rate is an indicator frequently used alongside appetite. Feed composition, disease, water quality and stress may also affect growth rate. Behaviour of fish is an important welfare indicator in hatcheries. Acute or chronic stress may produce altered behavioural patterns easily visible to staff regularly observing the fish. Visible behaviour may be related to feeding, swimming and respiratory rate, as well as aggression and abnormal behaviour in general.

Disease is a welfare indicator which may be applied both to groups of fish and individuals. Disease greatly affects welfare as it is linked to negative experiences such as exhaustion or discomfort/pain. Some infectious diseases, salmon pox being one of them, may infect a large proportion of affected fish groups and reduce welfare. As for mortality, the absence of disease does not equal satisfactory welfare but disease will always cause reduced welfare. Disease and disease control will together function as a retrospective indicator, and by identifying the pathogen or conditions (for instance insufficient water quality) causing the disease, one will be able to initiate rectifying measures and stop further spreading or negative effect on fish groups.

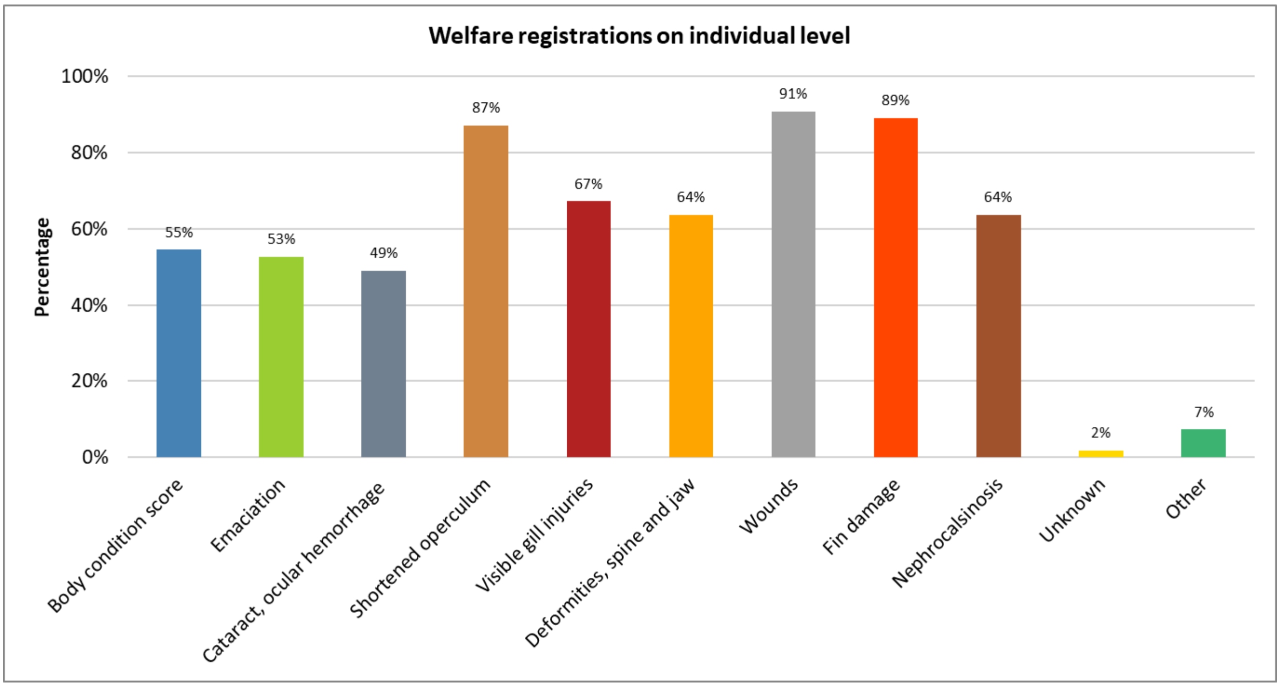


FIG 27. Criteria used to measure welfare in individual fish. (N=55)

When asked which criteria were used to measure welfare in individual fish, most gave wounds, frayed fins and shortened opercula as the most used indicators. More information on welfare indicators can be found in the handbook «Welfare Indicators for farmed Atlantic salmon - tools for assessing fish welfare» produced by the project Fishwell, financed by the Norwegian Seafood Research Fund.

FIG 28. Examination of gill status.

The survey asked which phases or conditions, based on experience, affect welfare and mortality in the hatchery on a scale from 1 (least critical) to 5 (most critical). Vaccination was ranked as the most critical procedure in terms of both welfare and mortality. 78 % gave vaccination a score of 3 or more concerning welfare, and 58 % scored the same concerning mortality.

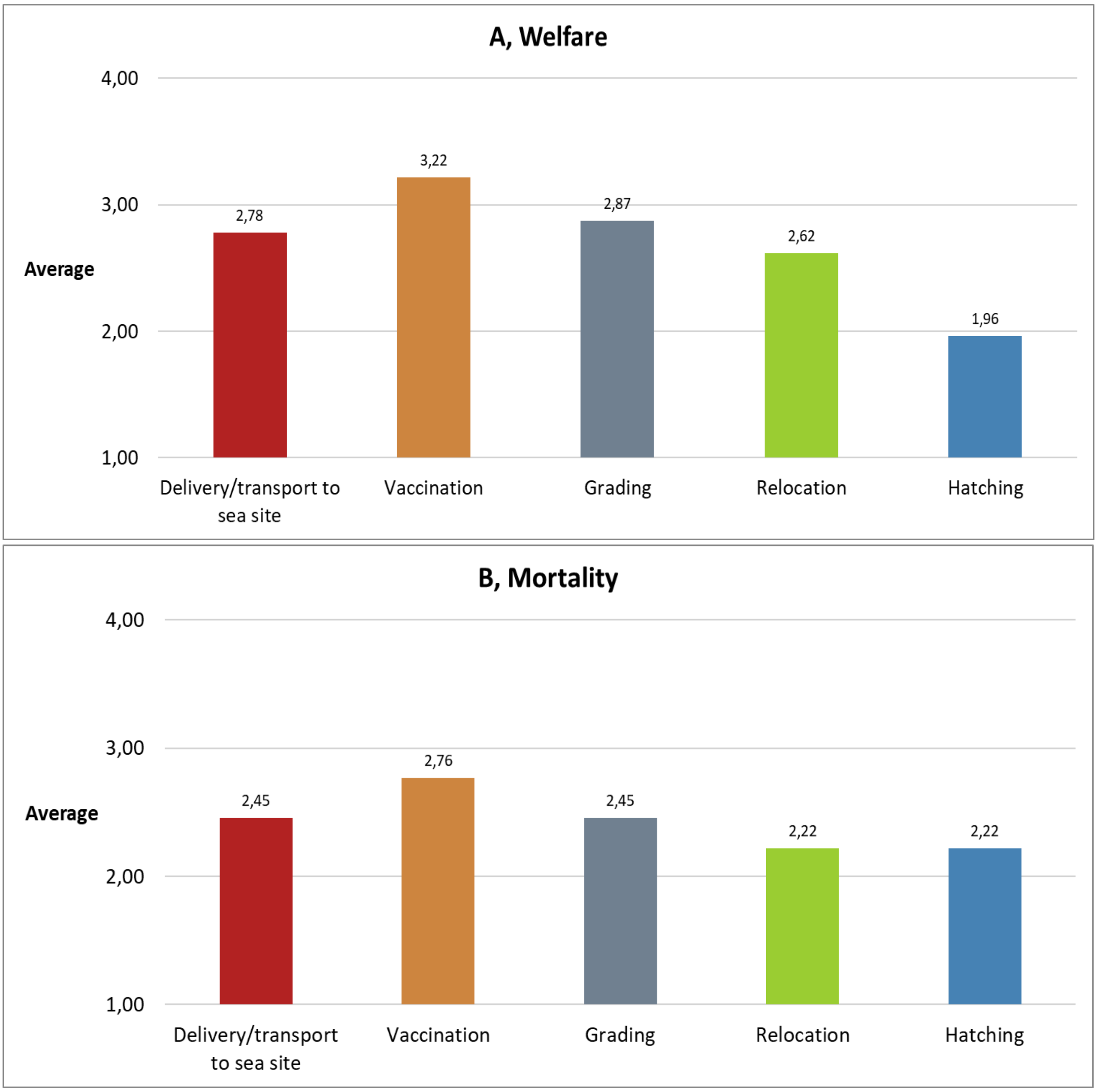


FIG 29 A and B show the average score of phases or conditions affecting welfare and mortality respectively on a scale of 1 (least critical) to 5 (most critical). (N=55)

When asked if the hatchery has experienced mortality or welfare issues due to technical failure in the last three years, four hatcheries say they have more than five times, 29 hatcheries maximum five times and 19 hatcheries say none. This demonstrates that failure of technical equipment constitutes a considerable welfare challenge in hatcheries.

Comments on welfare from respondents
«*Predators can be very stressful to fish in tanks outdoors. Herons and seagulls may find the fish tempting, while flocks of crows pick up spilled feed.* » The Aquaculture Operating Regulation requires production units to provide the best possible protection against attack from predators. Bird nets covering outdoor tanks help, but do not always provide complete protection.

FIG 30. Snow and ice on bird net.

Hygiene practices

Preventing infection from spreading within a hatchery is an important principle. That is why we asked if all-in-all-out stocking is practiced as an infection control strategy, and on which level. As the graph below demonstrates, almost all use this method. The category "other" consists of one hatchery attempting to create a physical barrier inside a unit.

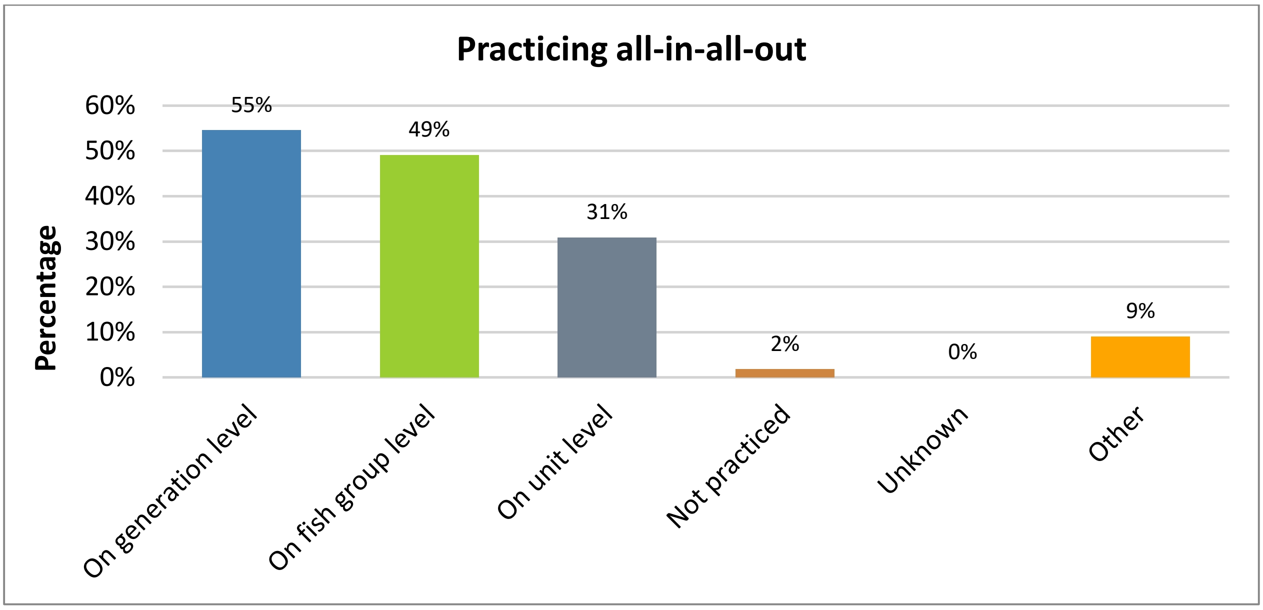


FIG 31. How is all-in-all-out practiced? (emptying of sections or units before taking in new fish). (N=55)

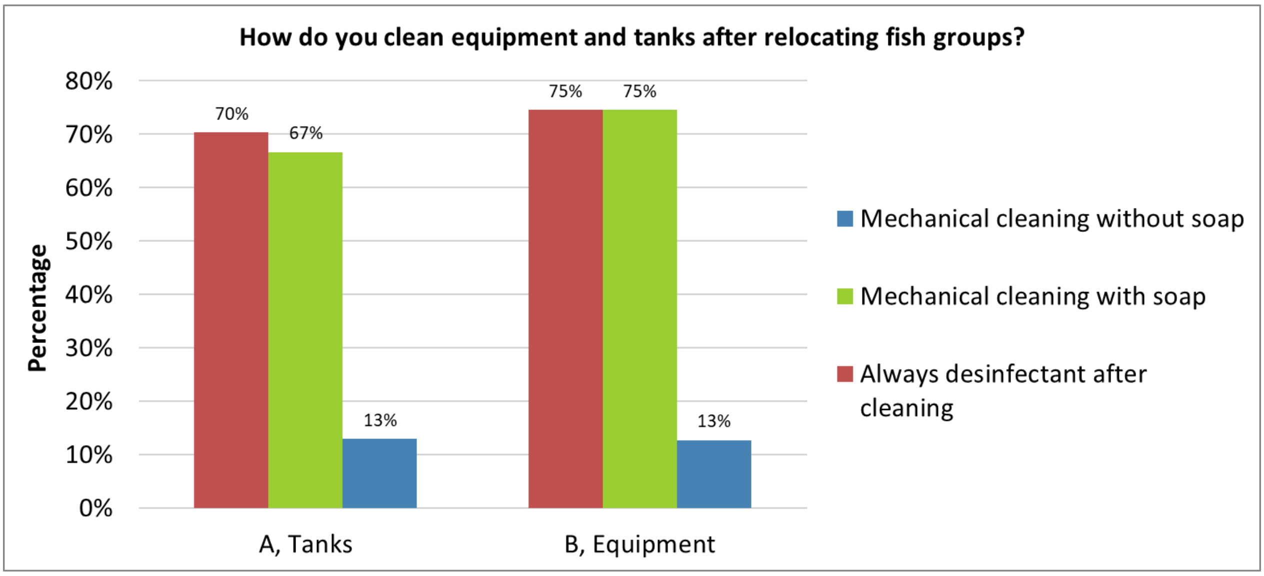


FIG 32. Cleaning of tanks and equipment after moving fish. (N=55 for tanks and N=54 for equipment).

FIG 33. Cleaning between batches of fish reduces the risk of transferring infection.

We also asked whether surfaces are allowed to dry before tanks or equipment are used after cleaning. 40 % of respondents let surfaces dry for at least a day as an extra precaution before transferring fish into the tank, while 44 % do not use drying systematically.

Whether equipment and tanks are always disinfected or not, was analysed as a risk factor for mortality but we found no significant effect.

In hatcheries with RAS technology a stable biofilter is considered by many producers to secure proper welfare and control of operating conditions. The survey included a question on when the biofilter is disinfected. Responses are listed below in figure 34.

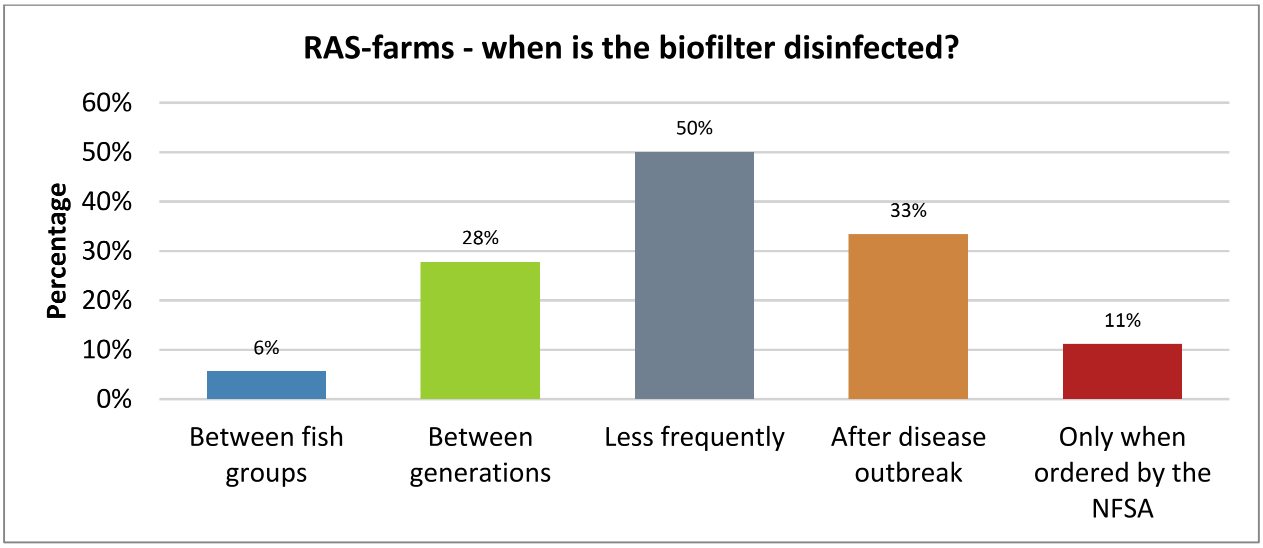


FIG 34. When is the biofilter disinfected in RAS-farms? (N =18)

When a biofilter is not disassembled and disinfected between each group of fish, the principle of all-in-all-out is broken and in terms of hygiene the production type has become continuous. As the graph shows, 33 % of the 18 hatcheries using RAS technology treat the biofilter after a disease outbreak, and some of these have also said they disassemble the biofilter between generations. We do not know enough about survival of pathogens, bacteria or viruses, in the biofilm. Some think the first phase, when the biofilm is building, is critical because of the increased risk of growth of unfavourable bacteria, while in a mature biofilter pathogens meet conditions too harsh for colonisation. There is ongoing research in this field. In the current situation, the Veterinary Institute regards continuous production as a risk. ISA (infectious salmon anaemia) outbreaks occurring shortly after smolts are transferred to sea indicate that infections may originate from the hatchery, but this has not been proven through epidemiological studies.

To disassemble a biofilter, the recommended treatment method is high pH followed by low. Of the RAS farms answering questions about disinfection of the biofilter, three used only high pH, five only low pH while five used both. Two of the hatcheries using both high and low pH also used ozone. The remaining hatcheries used ozone and chlorine dioxide, only chlorine dioxide or induced an increase in redox potential to above 650 mv.

FIG 35. Delivery of roe.

Roe may be a potential carrier of infection, so we asked where the roe comes from. Barely 30 % receive roe from within the company, while over 80 % buy roe from an external provider. This means that some hatcheries get roe from more than one supplier. We did not enquire about the cause for this but roe from different breeding companies may have different traits the hatchery wishes to utilise.

Regulations require all roe to be disinfected immediately after fertilisation. In addition to proper hygiene routines at stripping and fertilisation, disinfection constitutes a hygiene barrier between brood fish and roe and between roe producer and hatchery. Brood fish farms have sampling regimes in place for the brood stock to reduce the risk of transferring infection inside the roe. As well as disinfection of roe right after fertilisation, it is common to disinfect the roe again before delivery. Almost 90 % of the roe is disinfected before delivery, while barely 40 % of hatcheries disinfect roe upon arrival.

Disinfecting roe before introducing it into the hatchery was analysed as a risk factor for mortality. 19 practice this, 28 do not and for three the question was not relevant. We found no significant effect on mortality.

Purchasing fry is considered a risk factor in terms of introducing infection into the hatchery. Just over 70 % did not introduce fry, and were only raising fish from their own batch of roe.

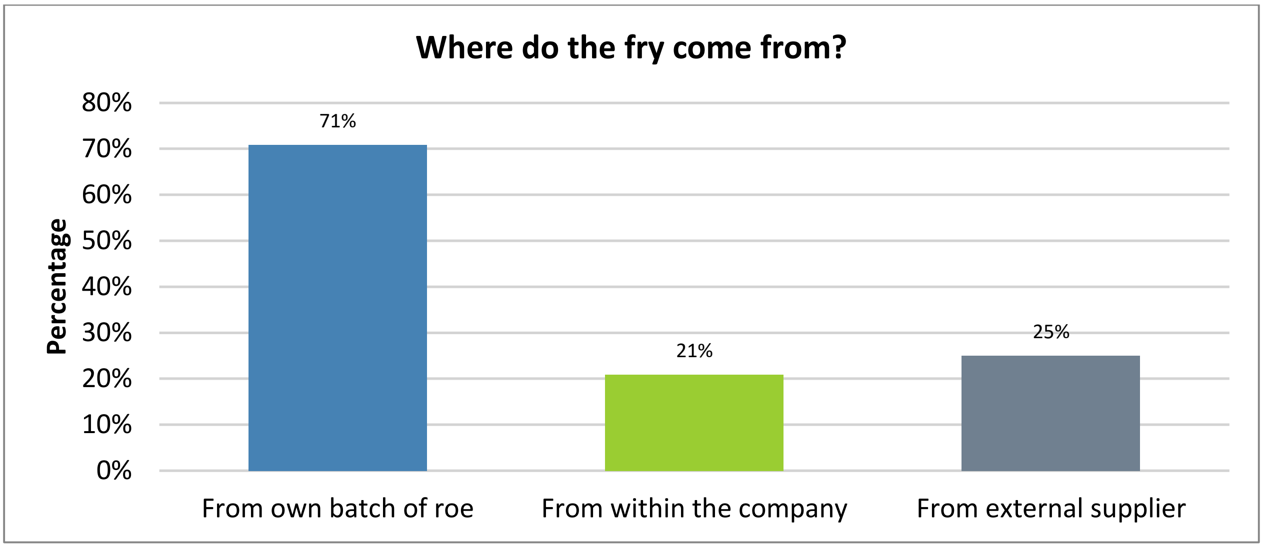


FIG 36. The proportion of hatcheries raising all the fry from their own batch of roe, and those receiving fry from other hatcheries either from within the company or an external supplier.

Those who purchase fry appear to also receive fry from more than one hatchery, which again increases the risk of introducing infection. Unlike roe, fry cannot be disinfected.

Frequent removal of dead fish is important in order to reduce the risk of spreading infection. This is done in all hatcheries. Removing moribund fish is also done frequently - it is beneficial in terms of both hygiene and welfare. Here everyone seems to have suitable routines. 60 % of hatcheries have automated removal of dead fish from the tanks. This will also collect moribund fish. When functioning well, these systems clear away dead fish without disturbing the remaining fish. All hatcheries report that they count the exact number of dead fish. Numbers reported to the Norwegian Food Safety Authority should therefore be accurate. Presumably, this is during normal operating conditions, as it is an impossible task during mass mortality when fish are weighed and the number calculated based on average weight.

Almost 90 % of hatcheries have a digital management system, meaning a software program for registering the production data. The system provides an opportunity to trace everything that happens to roe and fish in the hatchery, plan production and report to the NFSA or others.

Production and utilisation of farm sites

The number of smolts produced varies greatly between hatcheries that replied to the survey. A distribution of the number of smolts produced is presented in table 5.

TABLE 5. The number of smolts produced annually in hatcheries that replied to the survey. (N=51)

Smolts produced	Distribution of responses
< 1 mill	22 %
1 - 5 mill	63 %
5 - 10 mill	12 %
> 10 mill	4 %

The hatcheries were asked if they know the percentage of incubated roe that become smolts, and 78 % said they did. The percentages of roe reaching the smolt phase are listed in table 6.

TABLE 6. Percentage of incubating roe reaching the smolt phase. (N=38)

% smolt yield	Distribution of responses
60-65	5 %
70-79	18 %
80-89	58 %
>90	18 %

The density of fish in tanks affects water quality and fish welfare. The regulations state that densities in hatcheries must be reasonable and adjusted according to the water quality, behavioural and physiological needs of the fish, health status, production type and feeding technology. Accordingly, there are no exact limits on density but in connection with the water quality inspection campaign the NFSA conducted in hatcheries in 2012-2014, they stated that smolt producers should define their own upper limits specific to each hatchery.

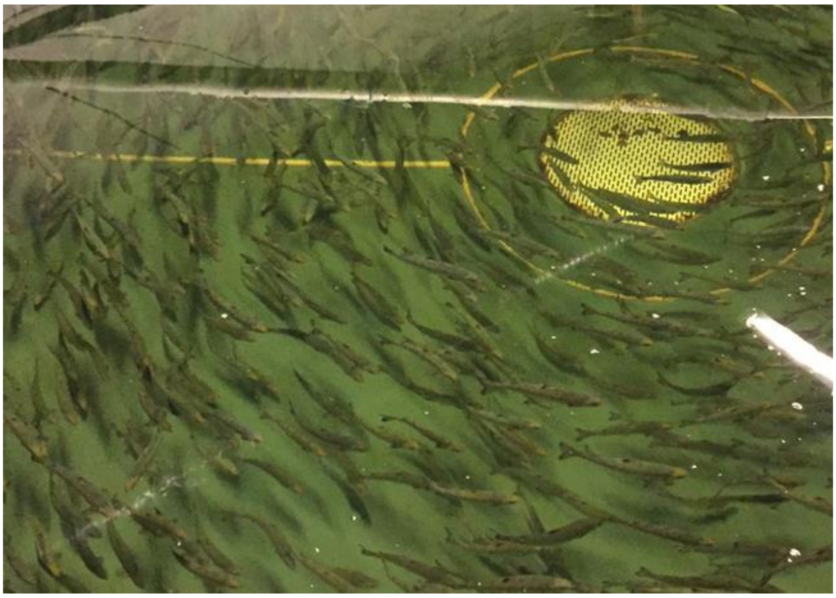


FIG 37. Fish tank with low density.

The survey asked about the maximum density limits during different phases of production, as defined by each hatchery. It is evident that most have set a maximum limit for the different phases but that this varies significantly between hatcheries. The answers were not given in the same unit, which makes comparison difficult. It demonstrates, however, that the hatcheries had set very different upper limits for density in the various production phases. In the first-feed phase the limits vary between 30 and 50 kg/m^3. Other hatcheries use number of fry/m^2 because they want to increase the probability of a large enough water surface for all fry to access food. Limits vary between 7.500 to 18.000 fry/m^2. In the ongrowing phase the limit for fish density varies from 30 to 85 kg/m^3, and from 50 to 85 kg/m^3 during smoltification. However, densities must always be viewed together with water quality and exchange rates in the tanks. It must be added that too low densities are not optimal as the salmon become more aggressive.

FIG 38. For yolk sac fry it is also important to have optimal water quality and temperature to avoid developmental anomalies.

Temperature is an important factor concerning fish welfare in all stages of the life cycle. Since salmonids are poikilotherms, the water temperature affects their metabolism and physiology. The temperature will also affect the amount of oxygen dissolved in the water. The optimal temperature depends on the life cycle stage of the fish. Too high or too low temperature may affect welfare differently. One example is that water temperature above 8 °C in the roe phase will increase the prevalence of deformities. The optimal water temperature range is summarised in Fishwell (3) and is 10-14°C for fry, 12-14°C for parr and 7-14.3°C or 10-13°C for smolts. Other investigations show that 12°C is the maximum limit in the first-feed phase to prevent spinal deformities from developing in the hatchery and manifesting during the sea phase (4).

FIG 39. Shortened operculum may be caused by too high temperatures during the roe phase.

Consequently, we posed the question: «What is your maximum temperature limit during different production phases? ». For first-feeding the minimum temperatures were between 5 and 13.5°C and the maximum 11 - 17°C. For ongrowing the minimum temperatures were 1.5–14.5°C and the maximum 12-18°C. For smolts the minimum was 0.1-14°C and the maximum 12-20°C.

Not all hatcheries have the possibility to control water temperature during all developmental stages, and are therefore at the mercy of the raw water temperature. In hatcheries with RAS technology, the opportunity for regulating water temperature is often greater. Still, we observe that the limits set by the hatcheries themselves deviate from the optimal temperature ranges.

FIG 40. Developmental anomalies.

The hatcheries were also asked if they manage to stay below the maximum temperature and density limits. 22 % said "Yes, always", 76 % "Yes, usually" and 2 % "No" (N=55).

They were asked how many times the fish are usually graded before transfer to sea, or alternatively relocated to a unit for production of large smolts. The replies are illustrated in figure 41.

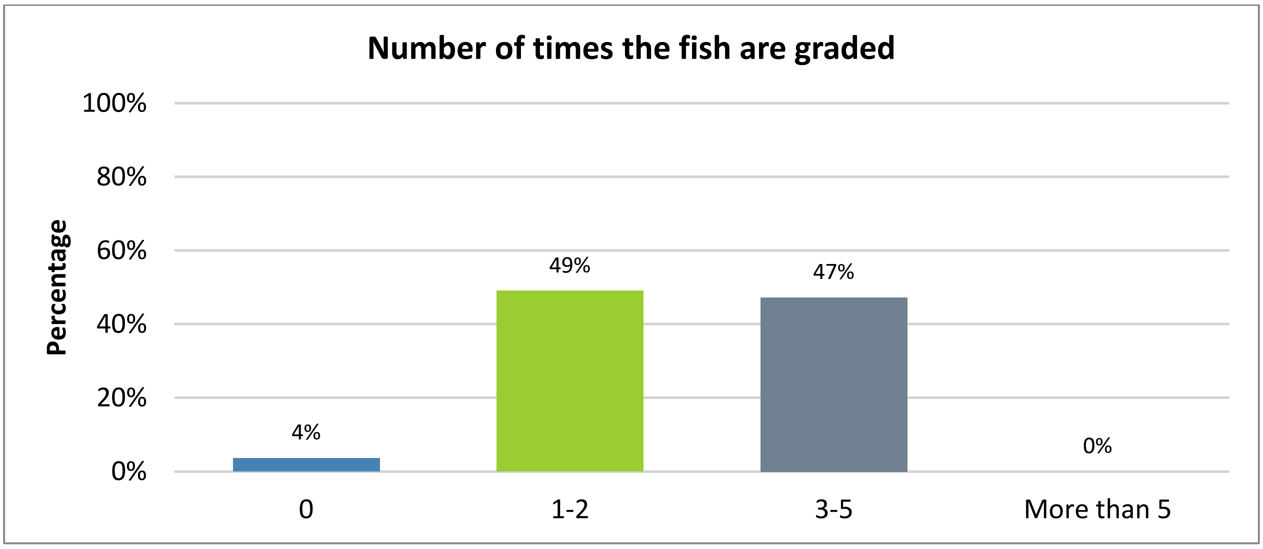


FIG 41. How many times are the fish usually graded before transfer to sea, or alternatively relocated to a unit for production of large smolts. (N=55)

Grading fish can be necessary in order to achieve even-sized individuals in a fish group, and may help improve welfare as it is easier to adjust the environment and feeding in a homogenous group. Yet, grading remains a stressful situation for the fish because it involves handling, pumping and relocation.

The number of times the fish are graded was analysed as a risk factor for mortality. For the analysis, responses were separated into two groups; those who grade 0-2 times and those who grade 3-5 times. We found significant effect on mortality.

The smolt phase is probably one of the most vulnerable phases in a salmon's life, and simultaneously it goes through considerable changes in environment. In nature, the transition from being a freshwater fish to becoming a saltwater fish is governed by light and temperature. In farming conditions, we manipulate and control this without fully understanding the consequences. At the same time, we keep a larger number of individuals at higher densities than found in nature, which may negatively affect stress levels and health status.

The survey asked how smoltification is controlled. The answers are illustrated in figure 42.

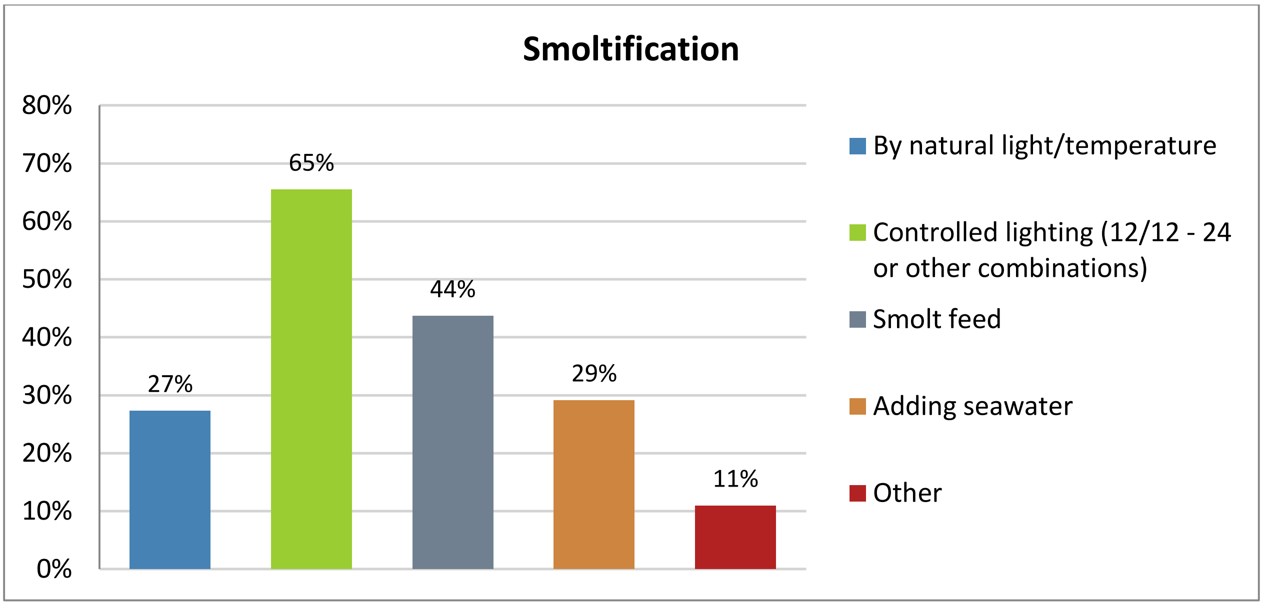


FIG 42. How is smoltification controlled? (N=55)

Preventative treatments and disease

The hatcheries were asked about the occurrence of different pathogens and their significance in terms of mortality. The significance was categorised into four groups: never detected, detected/but negligible or low mortality, detected/with moderate or high mortality and unknown. The results are illustrated in figure 43.

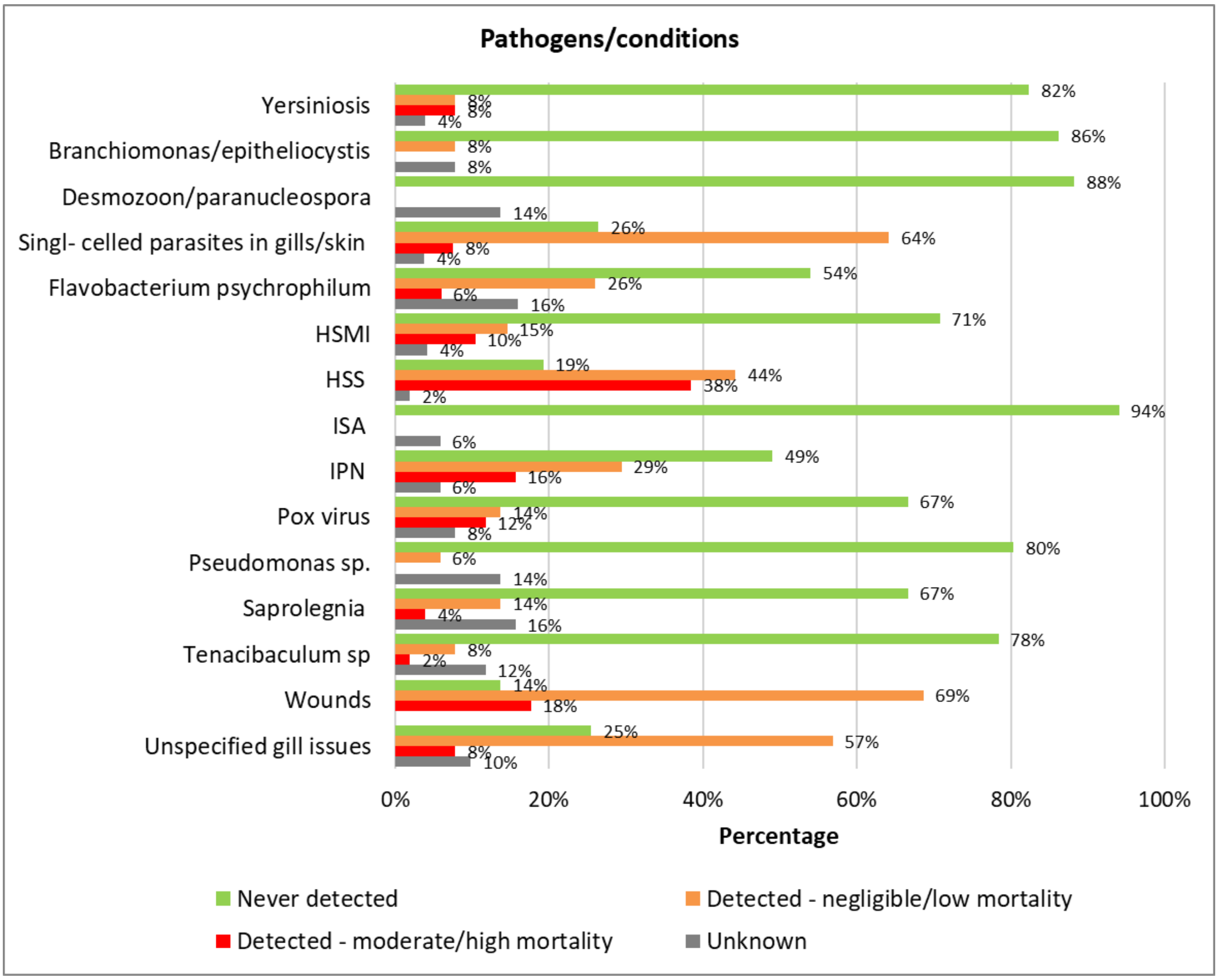


FIG 43. Occurrence of selected pathogens or conditions in hatcheries that filled out the survey. Single-celled parasites on gill/skin = Costia/Trichodina and others, HSMI = Heart and skeletal muscle inflammation, HSS = Haemorrhagic smolt syndrome, ISA = Infectious salmon anaemia, IPN = Infectious pancreatic necrosis, Pox virus = Salmon gill pox virus (SGPV).

FIG 44. Salmon with HSS, haemorrhagic smolt syndrome.

Of the conditions associated with moderate or high mortality, the five most frequently listed are HSS (haemorrhagic smolt syndrome) (38.5 %), wounds (17.6 %), IPN (15.7 %), pox virus (salmon gill pox virus) (11.8 %) and HSMI (heart and skeletal muscle inflammation) (10.4 %). Conditions detected and associated with negligible or low mortality, the five most prevalent are wounds (68.6 %), single-celled parasites on skin/gills (64.2 %), non-specific gill disorders (56.9 %), HSS (44.2 %) and IPN (29.4 %).

Hatcheries using seawater and hatcheries only using freshwater were compared to identify possible differences in prevalence of different pathogens and conditions. This was performed by calculating the most frequently detected pathogen/condition associated with moderate or high mortality (percentage = share of hatcheries). The results are listed in table 7. 37 of 55 respondents said they use disinfected seawater.

TABLE 7. Comparison of selected conditions associated with moderate or high mortality in hatcheries, with and without the use of seawater.

Pathogen/ condition	HSS		Wounds		IPN		Pox		HSMI	
With seawater: adding seawater during production	with seawater	without seawater	with	without	with	without	with	without	with	without
N= number of respondents	N=36	N=16	N=36	N=15	N=36	N=15	N=36	N=15	N=34	N=14
Never detected	13.9%	31.3%	16.7%	6.7%	47.2%	53.3%	64%	73.3%	64.7%	85.7%
Detected, negligible/low mortality	52.8%	25%	63.9%	80%	30.6%	26.7%	17%	6.7%	20.6%	0
Detected, moderate/high mortality	36.1%	43.8%	19.4%	13.3%	16.7%	13.3%	14%	6.7%	11.8%	7.1%
Unknown	2.8%	0	0	0	5.6%	6.7%	5.6%	13.3%	2.9%	7.1%

The number of respondents varied for the questions concerning pathogens/conditions, with 1-4 non-replies. This was taken into account when calculating the prevalence. The numbers must be interpreted with caution as there are about twice as many facilities using seawater as those who do not, but they may still provide insight. The number of cases of HSS (with negligible to high mortality) in hatcheries using seawater totals to just below 89 %, while for hatcheries not using seawater the number is just below 69 %. For wounds, the numbers are just above 83 % and 93 % respectively. For IPN the numbers are 47 % and 40 %. For pox virus the numbers are 31 % and just above 13 %. For HSMI the numbers are just above 32 % and 7 %. The numbers for HSS in hatcheries using seawater are artificially high as two of them ticked off two options: detected with negligible/low mortality and moderate/high mortality.

The numbers from the survey show that HSS, which manifests around smoltification, is detected more often in hatcheries using seawater, in spite of the fact that adding seawater or salt is used to reduce the prevalence and degree of HSS. The cause of HSS is still unknown but we expect research on this disease to start soon. There is a higher frequency of pox virus detection in hatcheries using seawater. Based on experience, pox virus/ salmon gill pox virus is found in farmed fish during both the freshwater phase and after transfer to sea. The higher frequency of pox in hatcheries using seawater does not necessarily indicate that the infection is spread by seawater. HSMI is a viral disease caused by piscine reovirus (PRV). The disease HSMI usually occurs during the first year at sea but the virus is detected in hatcheries with increasing frequency. Detection of virus does not necessarily equal clinical disease.

Vaccination of farmed fish in Norway has reduced the number of outbreaks caused by historically important bacterial diseases during the sea phase to practically zero. Indirectly, vaccination has also led to reduced losses, significant reduction in the use of antibiotics and improved fish welfare during the sea phase. Vaccination has however several side effects, caused by the vaccine itself as well as the vaccination process. Currently, vaccination of fish is mainly done by injection of vaccine into the abdominal cavity, but injection into musculature or dip and bath vaccines are also used. The process surrounding vaccination involves fasting, relocating, sedation and sometimes grading the fish. The extent of this makes vaccination a stressful procedure. In the survey we asked if the fish are vaccinated several times, to which 13 % said yes and 85 % said no (N=53). Vaccinating fish during smoltification can add considerable stress. 15 % said the fish were frequently in the process of smoltification and 2 % said always (N=53).

The survey inquired about the amount of fish discarded during vaccination (see table 8) and the three most important causes. To this question most replied “too small fish”, “spine and jaw deformities” and “shortened operculum”.

TABLE 8. The amount of fish discarded during vaccination. (N=49)

Discarded	Distribution of responses
<1 %	6 %
1 - 5 %	69 %
5 - 10 %	16 %
> 10 %	8 %

FIG 45. Manual vaccination. Today, a large proportion of fish are vaccinated by machines.

The hatcheries were asked whether they register cause of death during the daily removal of dead fish. 89 % say yes and 11 % say no (N=55). By registering this the hatcheries gain information enabling them to initiate rectifying measures as needed. The information provides an important foundation for evaluating the health condition of the fish. The hatcheries were also asked to state the three most important registered causes of mortality, and the answers are illustrated in the word cloud below.

FIG 46. The most important registered causes of mortality.

HSS was analysed as a risk factor for mortality. 16 hatcheries gave HSS as one of the three most important causes of mortality, and 37 did not list HSS at all. We found no significant effect of HSS on mortality.

When asked if destruction of fish during the production cycle is planned in advance, 27 % reply “Yes, always”, 38 % say “Yes, usually”, 33 % say “No” and 2 % “unknown” (N=55). Inquiring after the criteria for destruction showed that 58 % introduce more roe than needed, and 68 % say the fish never reached the correct size in time. 25 % give other criteria, among other things they mention fish that have not undergone smoltification at the time of transfer to sea, fish that will become runts at sea due to wounds, shortened operculum, spine deformities and other welfare related causes. Sudden change in scheduled production is also mentioned.

TABLE 9. Amount of fish (%) destroyed over the course of a production cycle. (N=31)

Destruction	Distribution of responses
<5 %	23 %
5 - 10%	32 %
10 – 15%	26 %
>15%	19 %

FIG 47. Wounds are a problem at both low and high temperatures, as well as when adding seawater.

Main conclusions and advice

Mortality as a welfare indicator
Mortality in itself is an indication of poor welfare in the hatchery. On a population level it is a simple welfare indicator as it is already registered in all hatcheries, and may potentially be a beneficial tool for the hatchery itself, authorities and research. If combined with causes of mortality it will serve as a suitable tool in order to implement rectifying measures where necessary. However, mortality does have some limitations as a welfare indicator for individuals that are already dead. Furthermore, a lack of mortality is not the same as good welfare, as fish may for instance be sick or suffer from reduced welfare for a long time without dying.

Summarised quality of reported data from hatcheries
The data currently reported by hatcheries are not of adequate quality. The quality control of reported data is probably insufficient and may be too inaccurate for measuring welfare properly. The requirements for reporting should be amended. Authorities are working towards improved reporting regimes. Relatively small alterations may lead to great improvements, for instance enable observation of developments in hatcheries over time and detect sudden incidents of high mortality. Since most producers already use software solutions to register mortality and causes of mortality, altered requirements will most likely not cause an increased workload. It does however require a new reporting module to be developed and integrated in the software.

It is recommended to alter the following reporting requirements:

- Reports should represent fish groups, where every group has a unique ID that can be traced throughout the entire production (also during grading, translocation and at sea).
- Reporting should occur as frequently as possible, at least weekly and preferably daily.
- Define the numbers reported more accurately; stock is the number of fish in the hatchery on the day of reporting.
- Dead fish should be categorized based on cause of death, and it should be clearly defined what is included in the mortality count, such as destroyed, discarded and moribund fish.

Surveying mortality counts and estimating mortality in hatcheries
The report provides an overview of the average number of dead per weight category per month. The average monthly mortality varies from 0.7 to 2.4 %. From 2015 to 2018 there was a trend towards higher mortality. Especially fish belonging to the smallest weight category (<3 grams) have the highest mortality. The average monthly mortality for the smallest fish is 2.4 % while for the other categories it is between 0.5 % and 1.25 %. Since mortality varies greatly between hatcheries, it indicates that many hatcheries have room for improvement.

Production parameters affecting mortality counts
Due to problems related to data quality of reported mortality counts, there are few risk factors available for analysis but stock size is one of them. The analysis shows that the number of fish in each weight category per site does not affect the average mortality of that group. We chose some of the most important production parameters from the survey and analysed the connection between these and mortality, but found no significant correlation. This may be due to the quality of data as previously described. This also makes it difficult to link mortality profiles to where and when the major health and welfare challenges occur in the production cycle.

Production parameters considered most suitable for future field-testing of welfare improvements in hatcheries
By extraction of average mortality from reported data, it is evident that fish under three grams had the highest mortality. One may speculate that this is due to relocation from hatching unit to tanks and first-feeding. Being moved from the protection of “grass mats” in hatching units to open tanks is a considerable change. Even though one can add hiding places to the first-feed tank for the first few days, the fry are suddenly living in an “open world” with constant light. The fry are small, about a couple of centimetres long, and the size of feed particles is of course adjusted accordingly. In order for all fry to have the opportunity to develop, the feed must reach the fry where they are, and in sufficient amounts while at the same time avoiding overfeeding which diminishes the water quality. One respondent says overfeeding can easily create muddy water in the tanks, which in turn may cause inflammation of gills and increased mortality. Insufficient feeding however, will lead to irregular development of fry and a certain number of runts. High mortality in fish under three grams may be due to timing of relocation to tanks, density, feed quality, feed distribution, water quality, currents, tank design, temperature, diseases and deformities.

The ability to control temperature, especially during early developmental stages, is important to secure normal development of the spine and operculum, and possibly also internal organs. Spine deformities discovered in the seawater phase may originate from the roe/first-feed phase. Temperature is not necessarily the only risk factor for malformations.

High densities of fish are common. Density alone does not necessarily cause visible consequences in terms of animal welfare, as long the water quality is optimal and stable. Experiments with larger fish in seawater have shown that densities of 75-100 kg/m^3 (5, 6) do not negatively affect welfare, presuming there is stable and optimal water quality and sufficient access to feed. In a commercial setting this would prove too difficult. Density and flow-through combined may however become an important welfare indicator. One respondent points out that the amount of oxygen used per kg fish produced may be more easily measured than flow-through rate in tanks and measurement of different water parameters.

Mortality varied greatly among the participating RAS farms. Since the reports to the Norwegian Food Safety Authority did not include information on RAS or flow-through systems, it was not possible to identify risk or success factors specific to RAS farms. At Tekset 2019, H_2S toxicity was named as a risk factor requiring further investigation, particularly in hatcheries using seawater.

Risk assessment is important and in this respect the hatcheries responding to this investigation scored high - most employees working with the fish also participate in the planning of risk assessments and procedures. Working for fish welfare is also prioritized but the survey shows that the farm management must be willing to allow the extra time needed to observe the fish closely. A closer follow up of deviations reported to the NFSA may serve as a gateway for prioritising and systematising efforts aimed at welfare in hatcheries.

Changes in regulations concerning reporting is necessary. An effort must be made towards improving registration of dead fish and causes of death in order to gain an overview of the situation in hatcheries. Consequently, it will be possible to move forward targeting the biggest welfare challenges in smolt production. The desire to provide proper care for the fish is certainly present in the hatcheries. Experiences from hatcheries should necessarily be organized and made available. This provides an opportunity of experiences from different hatcheries to become useful knowledge shared by smolt producers.

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FIG 48. Transport pipeline for loading smolts aboard well boats.

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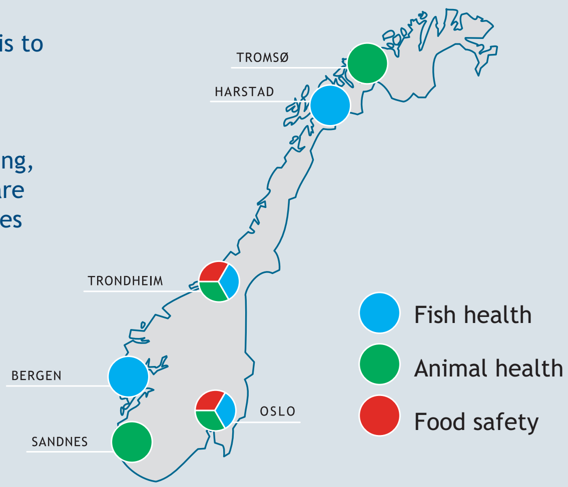
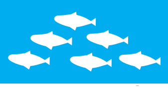
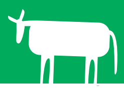


Fish health



Animal health



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