Risk assessments in the Norwegian aquaculture industry: Status and improved practice

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Abstract

The Norwegian aquaculture industry has the potential to become the country's leading ocean industry in the future. More than 99 % of the produced biomass is Atlantic salmon and trout. Norwegian fish farming is characterised by operations that are susceptible to changing weather, wind and currents, and face challenges in terms of safety for fish, personnel, environment and material assets. Previous research and accident analyses reveal an incomplete knowledge of risk factors during aquaculture operations. In order to raise standards of safety in the workplace, operators need to be aware of the challenges to safety in their work environment. The objective of this paper is to describe and discuss the current status of the implementation of risk assessments in the Norwegian aquaculture industry, according to Norwegian legislation and compared with recommended requirements in the Norwegian standard for risk assessments (NS 5814). This standard largely follows ISO 31000 for risk management. We also propose, test and evaluate an improved approach to risk assessment that will ensure stronger operator involvement. Our findings demonstrate that there are several gaps between the current practice and the standard. At the present time, operator involvement is not sufficient according to the regulatory requirements of internal control. Although the approach improves critical steps in the risk assessment procedure, it remains to be implemented in the fish farming industry.

Keywords: aquaculture; operational hazards; safety regulations; risk assessment.

1 INTRODUCTION

The Norwegian aquaculture industry has the potential to become the country's leading ocean industry in the future (Norwegian Ministry of Trade Industry and Fisheries, 2017). This ambition will require new biomass production sites to be established, and major environmental and technological challenges still have to be resolved (Bjelland et al., 2015). The aquaculture industry has become a driving force for the development of new technology, concepts and management strategies that meet the requirements for sustainable production in harsh environments. An important task in this development is to evaluate how safety risks in aquaculture can be reduced by integrating risk assessments in the engineering phase, as well as implementing new strategies for fish farm operations.

The fish farming industry is characterised by operations that are susceptible to changing weather, wind and currents, all of which affect the availability, safety and integrity of fish farms. Fish farming is thus a challenge to technology manufacturers, fish welfare and occupational safety. In Norway, being a fish farmer is the second most dangerous profession after capture fisheries in terms of rates of occupational injuries (Aasjord and Geving, 2009, Holen et al., 2017a) Between 1994 and 2014, 21 fatalities were registered, and the rate per 10,000 person-years worked ranged from 0 to 10.8 (Holen et al., 2017b), with an average fatality rate of 2.9. Since 2005, there have been nine fatalities during maintenance or other marine operations related to aquaculture production (SINTEF Ocean, 2018). Operations involving cranes or winches are the major contributors to these incidents (Holen et al., 2017b), many of which are performed as part of work-intensive delousing procedures. Lice and infections pose a hazard to fish welfare and health, as the treatment procedures cause stress and involve rough handling of the fish. Violations of the Animal Welfare Act will be investigated and may lead to fines (Norwegian Ministry of Agriculture and Food, 2009). Systematic regimes to monitor fish welfare and conduct delousing are mandatory (Norwegian Ministry of Trade Industry and Fisheries, 2016b, Food Safety Authority Norway, 2017).

Besides threatening fish welfare delousing also raises the risk for occupational injuries and for escape of fish. After years of growing numbers of escaped fish, action was taken after 2000 to reduce the number of incidents caused by structural breakdowns and technological failures (Jensen et al., 2010). Operational errors and structural deficiencies due to insufficient or missing safety barriers are now the most frequent causes of escapes (Directorate of Fisheries, 2017b). An analysis of farmed salmon and trout escapes between 2010 and 2016 has shown that holes in the net are the major direct cause, and these are mostly due to bad handling or conflicting integrity with the bottom weight system of the fish cage (Føre and Thorvaldsen, 2017).

Escapes are not only a threat to the environment, but also contribute to the negative reputation of the industry (Olsen and Osmundsen, 2017). Fish farmers report that personal safety may be set aside in order to prevent a- fish escape accident (Størkersen, 2012, Thorvaldsen et al., 2015). A study by Holmen and Thorvaldsen (2015) showed that the aquaculture industry lies behind comparable industries in implementing systematic risk management. Previous research and accident analyses reveal a considerable lack of understanding of the risks involved in marine operations in aquaculture (Holmen et al., 2017b, Holmen et al., 2017c, Holen et al., 2017a, Holen et al., 2017b, Jensen et al., 2010, Thorvaldsen et al., 2015, Føre and Thorvaldsen, 2017). In this context, fish farmers' knowledge of operational hazards, experience and skills are important organisational safety barriers. Risk assessments and personnel training may therefore be important safety factors. This calls for a more comprehensive approach to risk management in the fish farming industry. A recent study recommends that five dimensions of risks need to be assessed in a fish farm operation (Yang et al.). These are risks to personnel, material assets, fish welfare, the environment and food safety.

Risk assessment is a core activity of risk management and consists of identifying hazards, analysing and evaluating risks, and among outcomes are action plans for risk treatment during the design and operational phases of a production unit (ISO, 2018, Rausand, 2011). A starting point for the fish farming industry could be to implement improved strategies for thorough assessments of operational risks as a basis for developing effective preventive measures, as well as increasing workers' awareness of the risks inherent in daily work. Recognition of occupational hazards is fundamental in order to implement efficient safety measures in aquaculture (Moreau and Neis, 2009, Myers and Durborow, 2012). In Norway, it is a regulatory requirement that operating personnel are to be involved in the risk assessment process, in order to ensure that relevant workplace hazards are identified and understood by those actually performing the work (Norwegian Ministry of Labour and Social Affairs, 1996).

The objectives of the paper are to present the status of risk assessments in the Norwegian aquaculture industry, and thereafter to discuss how the implementation of risk assessment might be improved in order to fulfil the intention of the standard and of the regulations. Part of the study has been published previously in Holmen et al. (2017c), which is a brief presentation of the regulatory requirements for risk assessments in aquaculture operations, a summary of current practices and an recommended improved approach to hazard identification and risk analysis, in the Norwegian context. The present paper extends both the data material and the scope of the study by comparing current risk assessment practices step by step with the risk assessment process recommended by the standard NS 5814 (Standard Norway, 2008), which largely follows the international standard for risk management, ISO 31000 (ISO, 2018).

The paper is structured as follows: Section 1 introduces the aquaculture industry context and its safety challenges, as a background for the objectives of this paper. Section 2 presents requirements for risk assessments in Norwegian aquaculture regulations and standards related to risk assessments. Section 3 presents the results from a systematic analysis of the current practice for risk assessments and is followed up by a suggestion as to how the practices could be improved (Section 4). The results are discussed in Section 5, and the conclusions in Section 6.

2 Regulations and standards for risk assessments in Norwegian Aquaculture

2.1 The Norwegian fish farming industry

The Norwegian finfish aquaculture industry comprises all sizes of companies from large global enterprises to family-owned fish farms in small communities. There is also a growing number of manufacturers and providers of equipment, components, vessels and services to the aquaculture industry. Norway is the world's second largest exporter of fish after China, but the largest producer of finfish in marine and coastal environments (FAO, 2016). More than 99 per cent of the Norwegian total produced biomass is farmed Atlantic salmon and trout (Directorate of Fisheries, 2017a), which is the focus of this paper.

There are normally six to 12 circular plastic collar net cages in one fish farm(Jensen et al., 2010, Holen et al., 2017a). The number of cages differs according to the site and production license. Each cycle of fish is grown out in seawater for 18 months before it is slaughtered. The operations manager is responsible for both production and personnel safety. Each fish farm employs about three to six workers (in this paper also referred to as fish farmers or operators) who are responsible for daily inspections, feeding and maintenance. The feeding barge, which is the "operations centre" of the farm, contains rooms for equipment and feed storage, the feeding system, as well as offices, meeting rooms and accommodation for the workers.

Designated work vessels, from 8-15 m length overall (l.o.a.) and equipped with capstans and/or a crane, are used for inspection and maintenance of the fish cages. The daily inspections are performed in accordance with official regulations on aquaculture operations (Norwegian Ministry of Trade Industry and Fisheries, 2008), and are intended to ensure that the net cages are in order and to assess fish welfare. The operators perform such tasks as maintenance, removal of dead fish from the net cages and monitoring the amount of salmon lice on a sample of fish every week. Specialised service vessels and crews, either the company's own or belonging to subcontractors, are chartered for heavier operations such as mooring and delousing.

A wide range of equipment for monitoring and caring for the fish is mounted inside the net cage (Holmen et al., 2017a). Examples include hideouts (shelters) for wrasse (small size "cleaning fish" which feed on salmon lice), air tubes, cameras, gear for removal of dead fish and much more. The equipment may represent hazards to the fish or the net and has to be handled carefully if it has to be removed before an operation can start. During operations, extra devices and equipment may be needed; e.g. remotely operated vehicles (ROV), tubes for pumping fish or a remotely operated cleaning system positioned by a crane. All this extra gear adds complexity to the operations. Furthermore, aquaculture operations are not standardized, neither between companies nor between fish farms in different regions, and different equipment may be used, depending on what is available (Holmen et al., 2017a). All of these factors have consequences for the risk assessments, because hazards must be identified for each specific operation.

2.2 Regulations

The administration of the Norwegian aquaculture industry is fragmented as regards legislation and the regulatory authorities involved. Coastal area management, allocation of fish farm licences, planning and establishment of sites, inspection of fish welfare and health, food production and environmental protection are allocated to six different ministries and regulatory authorities. In certain areas the audits are delegated to regional or local community offices, which in turn increases the potential for differences arising in how cases are dealt with (Robertsen et al., 2016). The requirements regarding risk management in production are also fragmented (Holmen et al., 2017c).

Performing and documenting risk assessments for all aquaculture operations is mandatory, as are activities related to breeding and farming fish and keeping them in good health. Risk assessments are statutory and are imposed by five regulatory authorities: The Directorate of Fisheries, Food Safety Authority, Norwegian Maritime Authority, Norwegian Labour Inspection Agency and the County Administration. These bodies are responsible for the regulations regarding fish welfare, food safety, fish farm technical standard, vessel design and equipment, health, work environment and safety, and the environment. The relevant aquaculture legislation and regulations are described in Holmen et al. (2017c) and summarised in Table 1.

Table 1 Norwegian regulations, statutory acts and authorities sanctioning risk assessments in aquaculture.

Topic	Regulation Statutory Act(s)	Norwegian regulatory authority	Focus of risk assessments	Purpose
Fish welfare and health Food safety	Regulation on the operation of aquaculture production sites (Norwegian Ministry of Trade Industry and Fisheries, 2008) Regulation on internal control to comply with the aquaculture legislation (Norwegian Ministry of Trade Industry and Fisheries, 2004) Food Act (Norwegian Ministry of Health and Care Services, 2003) Animal Welfare Act (Norwegian Ministry of Agriculture and Food, 2009)	Food Safety Authority	Health control parameters and water quality. Assess risk of contamination of food for consumers.	Support technical, biological, economic and environmental sustainable aquaculture production. Promote good health and welfare for aquaculture species.
Fish escape prevention	Regulation on the operation of aquaculture production sites (Norwegian Ministry of Trade Industry and Fisheries, 2008) Aquaculture Act (Norwegian Ministry of Trade Industry and Fisheries, 2005)	Directorate of Fisheries	Minimise risk of fish escapes and implement systematic preventive measures.	Support technical, biological, economic and environmental sustainable aquaculture production.
Technical condition of fish farm	Regulation on technical requirements to floating aquaculture plants (Norwegian Ministry of Trade Industry and Fisheries, 2011)	Directorate of Fisheries	Assess risks during engineering, manufacturing, installation and operation of fish farm. Include risk of fish escape.	Prevent fish escape by securing the proper technical standard of the fish farms.
Vessel design and equipment; Safety management of daily operations	Regulation on construction and inspection of smaller cargo vessels (Norwegian Ministry of Trade Industry and Fisheries, 2015) Regulation on safety management for smaller cargo vessels, passenger vessels, fishing vessels (Norwegian Ministry of Trade Industry and Fisheries, 2016a) Ship Safety Act (Norwegian Ministry of Trade Industry and Fisheries, 2007)	Maritime Authority	Marine operations, vessel design and stability.	Ensure technical standard of vessels and equipment on board. Systematic, daily management and follow-up of identified risks.
Physical environment	Internal control regulation (Norwegian Ministry of Labour and Social Affairs, 1996) Working Environment Act (Norwegian Ministry of Labour and Social Affairs, 2005) Aquaculture Act (Norwegian Ministry of Trade Industry and Fisheries, 2005)	County Administration Directorate of Fisheries	Sustainability of the aquaculture location and risk for emissions to the surroundings.	Support continuous improvements in regarding the work environment and safety, and protection of the environment against pollution and a proper waste treatment.

Occupational health, environment and safety	Internal control regulation (Norwegian Ministry of Labour and Social Affairs, 1996) Working Environment Act (Norwegian Ministry of Labour and Social Affairs, 2005)	Labour and Inspection Agency	All physical, chemical and biological, organisational, psychosocial and ergonomic elements.	A safe and sound work environment for all workers.

2.3 STANDARDS

The requirements for the technical condition of fish farms are described in Norwegian standard NS 9415: Marine fish farms - Requirements for site survey, risk analyses, design, dimensioning, production, installation and operation (Standard Norway, 2009). Since NS 9415 in itself is not regulatory for the aquaculture industry, the Norwegian Ministry of Trade, Industry and Fisheries (2011) introduced the "Regulation on technical requirements for floating aquaculture plants" in order to ensure compliance with NS 9415. This regulation states that aquaculture installations shall comply with the technical safety level in NS 9415 (or similar) and this is to be certified by an accredited body. The Directorate of Fisheries is the controlling authority regarding the technical components of a fish farm. The standard NS 9415 refers to NS 5814 for risk assessments (Standard Norway, 2008), and the requirements for risk assessments in NS 5814 are thereafter brought into effect. For other areas the standard is voluntary, although some companies have linked their internal risk assessment requirements to NS 5814.

Table 3 shows the steps in the risk assessment process, according to NS 5814. This process is aligned with the risk assessment process of ISO 31000, although not identical.

3 CURRENT PRACTICE FOR RISK ASSESSMENTS

3.1 DATA COLLECTION

The methodological approach in this paper includes data collection from several sources of information; interviews and observations in the field, analysis of risk assessment documentation, as well as four workshops. The information obtained from participants in interviews and workshops has been treated anonymously and has been handled according to the principles of the Norwegian Data Protection Official for Research (NSD, 2018). The methodological approach is described in detail in Holmen et al. (2017c).

3.1.1 Interviews and observations

The interviews and observations aimed to assess the current risk assessment practices at fish farms and on board service vessels. Interviews with workers and observations took place during maintenance and/or daily operations in June and August 2015, June 2016, and March and November 2017 on board four service vessels and at five fish farms. The fish farms are owned by three of the largest Norwegian farmers of Atlantic salmon and located in the three northern aquaculture regions of Norway. Two of the sites are owned by the same company but located in different regions. The service vessels had been chartered to perform maintenance on fish farm structures and moorings.

The vessel crews, fish farmers and operational managers were asked about their involvement in risk assessment and to explain how this is implemented in work practices and safety precautions in daily operations. During the visits, samples of the risk assessment documentation were checked. Additional interviews with HSEQ staff and managers were conducted either by phone or in the informant's office. Table 2 shows the categories of informant, type and number of interviews.

Altogether 24 interviews were carried out, involving 30 persons from six Norwegian aquaculture companies (fish farmers and service providers). These companies vary in size from well-established enterprises with more than 1,500 employees to companies of less than 100 workers. Meetings were arranged with two regional management groups; the regional director, the technical manager, the production manager and the HSEQ coordinator in each of two regions of one company. The main purpose of these meetings was to present the findings from the observations at their production units.

During the meetings, the management was asked questions regarding implementation of risk management and mitigation measures.

Table 2 Informant categories, type and number of interviews.

Informant category	Individual interview at workplace	Individual interview by phone/in office	"Group interview" in office
Fish farmer	4		
Operational manager fish farm	2		
Service vessel crew	5		
Operational manager vessel	4		
HSEQ coordinator/manager	1	4	
Management group (4 persons each)			2 (8 persons in total)
General manager		2	
Total	16	6	2

The information gathered through the interviews and observations provided us with an overview of current practices, deficiencies and needs for improved risk assessment in aquaculture.

3.1.2 Documentation

Risk assessment documentation was also gathered from three fish farming companies, in order to identify how the risk matrixes and evaluation criteria were designed according to the regulatory requirements. The documentation is a combination of examples of risk assessment matrixes, descriptions of risk acceptance criteria, and written procedures describing how risk assessments should be performed in the company. This is summarised in section 3.3.

3.2 Analysis of current practices

This section presents the current practices of fish farming companies regarding risk assessments and compares them with the requirements set out in NS 5814. Table 3 lists the deviations between the recommended steps in the risk assessment process and the current practice in Norwegian fish farming. The qualitative data presented is based on interviews and documentation from six companies (see previous section). The company management is assumed to be committed to the process in their risk management policy. HSEQ staff is often responsible for developing templates or standard checklists as an assisting tool for the operational managers at the fish farms or managers/skippers on board the vessels, who are responsible for carrying out and documenting the risk assessments at their production units. A regional management, which may include a production manager responsible for the biological production, is usually responsible for the implementation of the risk management policies approved by the company's top management. Our study revealed that at some locations the risk assessments were conducted only at managerial level. Risk assessments should be performed before production starts and revised yearly or more frequent if changes are made to equipment, technical installations or operational procedures.

Table 3 The deviations between the recommended steps in risk assessment (RA) according to NS 5814 (Standard Norway, 2008) and the current practice in Norwegian fish farming. The right column specifies which position/management level in the company who is responsible for the step.

Recommended steps in risk assessment process	Deviations	Responsible in company
1. Planning		
1.1 Initiate process, define problem and scope	- RA is not performed before decisions are made. - There is no plan for the work. - There is no description of the background for RA, which parties are involved and how they could be affected.	Management (decisions) ↓ HSEQ staff (suggest, implement)
1.2 Organise the work, establish work group	- No verification of whether there is agreement between the work, the requirements of the standard and the management's specifications. - The working group's competence relevant for the RA is not documented. - The person responsible for RA is not necessarily familiar with the contents of the standard. - The management does not document that the RA has been carried out by competent personnel. - The management does not document that relevant stakeholders are involved.	Production manager ↓ Operational manager (Assisted by HSEQ staff on request)
1.3 Choose method and data sources	- Company internal templates for RA are used, but the choice and sources of data for risk analysis are not verified in writing.	HSEQ staff (preparation of RA template)
1.4 Establish description of system and object to be analysed, document conditions and assumptions	- The object of the analysis is not described in detail. - There is no evaluation of whether premises, assumptions and simplifications are reasonable and realistic.	Operational manager
2. Risk analysis		
2.1 Identify hazards and undesired events	- There is no documentation regarding potential undesired events that have not been not further analysed (e.g. not relevant, minimal risk).	Operational manager
2.2 Analyse causes and likelihoods	- The list of causes identified for each undesired event may not be complete. - RA of technical systems are not complete with respect to human and/or organisational aspects. - There is no documentation verifying that the analysis has been performed at an adequate level of detail based on the objectives and limitations of the RA, decisions to be made, and availability of relevant/accurate data.	Operational manager
2.3 Analyse consequences	- Short-term consequences are dealt with more thoroughly than long-term consequences.	Operational manager

	- There is no systematic consideration of existing measures which reduce the severity of the consequences, or of other conditions that could influence the outcome of an undesired event. - There is insufficient documentation that verifies that the analysis is concluded at an adequate detailing level based on the objective and limitations of the RA, decisions to be taken, and availability of relevant/accurate data.	
2.4 Risk description	- The uncertainties are not assessed and included in the risk description.	Operational manager
3. Risk evaluation		
3.1 Evaluate risks against risk acceptance criteria	- In some cases, the risk may be underestimated.	Operational manager
3.2 Identify mitigating measures and their risk-reducing effect	- The list of measures identified to eliminate, reduce likelihood or consequence of an incident may not be complete. - There is no documentation of the expected effect of measures.	Operational manager
3.3 Document and conclude	- There is no documentation of conclusions from the RA to be used as the basis for risk management. - The documentation neither refers to literature/data sources, nor documents the work process and the choices taken regarding methods, limitations, and possible need for further work. - Deviations from the standard is not justified.	Operational manager

The findings are summarised and commented in section 3.5.

3.3 RISK MATRIX DESIGN AND RISK ACCEPTANCE CRITERIA

The standard for risk assessments, NS 5814 (Standard Norway, 2008), states that the description of risks may be quantitative or qualitative, i.e. it is up to the company to choose the preferred method (Table 3). All the companies that participated in this study use qualitative risk analyses and risk matrices to describe risks. The prevailing approach is to describe risk as the product of potential consequences and likelihood. The result is evaluated against risk acceptance criteria expressed by the colours green (acceptable risk - no further action needed), yellow (lowest acceptable risk – consider additional safety measures) or red (inacceptable risk – risk-reducing measures shall be implemented). The risk priority numbers (RPN) are suggested by personnel in the HSEQ department and decided by the management. One of the companies performs risk assessments along eight consequence dimensions: fish health, fish welfare, fish escape, human health and safety, reputation, food threat, food safety, environment. Table 4 shows examples of risk-matrix designs in three companies. The consequences depend on the area analysed, and in Table 4, the consequences for health, safety and work environment (HSE) are used for comparison.

Table 4 Risk matrix design and risk evaluation criteria as defined by three fish farming companies.

Company no	Size	Type of risk	Consequence priority number (example HSE)	Likelihood	Risk priority number (RPN)
1	5x5	Fish health, fish welfare, escape, HSE, reputation, food threat, food safety, environment	1=Insignificant, no absence 2=Minor, absence < 3 days 3=Significant, absence 3-14 days 4=Serious, long time sick-leave, permanent injury 5=Catastrophic, fatal	1=Very unlikely (once every 10th year or less) 2=Less likely (once in 1-10 years) 3=Likely (once per year) 5=Quite likely (1-10 times per year) 10=Very likely (More than 10 times per year)	≤ 4 Acceptable risk 5<10 lowest acceptable risk. Preventive measures shall be implemented, further mitigations to be considered. ≥ 10 Unacceptable risk. Risk-reducing measures must be identified and implemented before operation can start.
2	6x6	Fish health, fish welfare, HSE, food safety, external environment, environmental aspects	1= No injury 2=Minor injury, no medical treatment 3=Minor injury with medical treatment 4=Serious injury 5=Serious injury, long time harm 6=Fatal	1=Not likely at all 2=May have happened 3=Yearly 4=Monthly 5=Weekly 6=Daily	≤ 6 Acceptable risk 8-16 Lowest acceptable risk. >16 Unacceptable risk.
3	5x5	Fish welfare, escape, personnel safety, reputation, food safety, environment	1=Very low, no injury 2=Low, injury with no absence or reported to NLIA[1] 3=Medium, absence injury and/or reported to the NLIA 4=High, permanent injury 5=Very high, permanent disability or death	1=Extremely low, never heard of 2=Low, have heard of 3=Likely, may happen once 4=Much likely, may happen a few times 5=Very likely, may happen several times	≤ 4 Acceptable risk 5<15 Risk-reducing measures may be implemented ≥ 15 Unacceptable risk. Risk-reducing measures shall be implemented.

[1]Norwegian Labour Inspection Agency

3.4 Informal Risk Analyses

Safe job analysis (SJA) is a risk-analysis method that is performed to identify potential hazards during operations, and to implement measures which reduce the risks (Rausand, 2011). SJA should ideally be carried out by the work team prior to the operation, and is usually carried out for less frequent, hazardous operations, dangerous routine jobs or new procedures. Other triggers for a SJA might be a new vessel or new operators participating in a complex operation. Important objectives of SJA are to make operators more aware of inherent risks, and to discuss possible actions to mitigate undesired events.

SJA was originally a process comprising several steps and with thorough documentation of the risk assessment of each task within the operation (Rausand, 2011). Some fish farm companies have implemented a template for a SJA "light", which assumes that a risk assessment for the work operation or procedure already exists. The "light" version is then a way to remind the personnel of the operational risks, as well as to update the procedure if it has been a while since it was last used.

One of the companies in this study has a written procedure for SJA, which states that SJA must be carried out ahead to all work operations that a) are not already described in a procedure; b) have not been conducted for a long time; and c) for which personnel lack relevant experience/training. Another company calls all personnel in to a "pre-operation meeting", in which the risk assessments are presented and a memo subsequently documents the content of the meeting. Some operational managers have an informal meeting which has previously been referred to as the "cup of coffee chat" (Holmen et al., 2017c). Although such meetings are not a SJA as described in the literature, the intention of the risk analysis method is achieved: bringing together all operators, both in-house and hired services, reminding them of the operational hazards, discussing responsibilities, sharing knowledge and agreeing on safe job practices. When this study began, SJA was new to several of the companies, and their staff had little knowledge of how to run a SJA. However, during the two years of data collection, more companies have started to do SJAs regularly and have established internal templates or checklists as a tool for their operations managers.

Some aquaculture companies report that planning operations is a challenge, involving complexities due to changes in the weather, attacks by fish parasites and other biological factors, as well as the availability of experienced operators, well-boats or other essential subcontractor services. The industry is therefore seeking tools to support good practices for operational planning. A systematic SJA process in good time could therefore be a useful means of mapping and identifying the most important risk factors involved in the operation.

3.5 Summary of findings

The largest gaps between the recommended steps for risk assessments in NS 5814 and current practice were found in the planning phase, and regarding the involvement of workers in the analysis phase. In many cases, risk assessments were not properly planned or given sufficient priority during day-to-day farming and maintenance tasks. The involvement of operators turned out to be in sufficient or completely lacking. This is an important part of the risk assessment procedure that needs be improved to achieve the regulatory requirement of operator involvement in internal control (Norwegian Ministry of Labour and Social Affairs, 1996).

In the risk analysis step, the hazards were listed but the chains of events were not thoroughly described. Nor was it clear how well the risk assessments were related to actual work practices. The persons responsible for the risk analyses often had little if any documented formal training. Moreover, the methods for identification of hazards were often based on templates, which might not be connected to the different operations which are the sources for the potential hazardous events. In general, documentation of details in the work process, choices and limitations taken, was not satisfactory according to this standard.

All the companies that participated in our study employed semi-quantitative descriptions of risks in matrices, and used worksheets to keep track of possible hazards and their sources, causes, likelihoods and consequences. The number of types of risk as well as the design of the risk matrices differ somewhat between the companies. Neither the consequence priority numbers nor likelihood grading (expressed as frequencies) are standardised within the industry. Hence, the risk priority numbers (RPN) vary significantly and are not comparable between the companies.

Sufficient involvement of operators may not be prioritised when there are practical tasks that need to be done. This is compensated for to a certain extent by the introduction of safe job analyses (SJA). An SJA is carried out prior to operations that are regarded as being of particularly high risk, because they are rarely performed, previously described in written procedures (e.g. introducing new equipment or techniques), or if the personnel have only limited experience of the particular operation to be performed. SJA was gradually implemented in the fish farming industry during the study period.

4 IMPROVING RISK ASSESSMENT PRACTICE - CLOSING THE GAPS

4.1 A NEW APPROACH

In this section, suggested improvements are first described for each main step of the risk assessment process, as described in NS 5814 (Standard Norway, 2008): planning, risk analysis and risk evaluation(Table 3). . This is then summarised in a stepwise recommended approach aimed at closing the most essential gaps identified during the comparison with the requirements for risk assessments in NS 5814 (previous section).

4.1.1 Planning

To ensure that risk assessments are well anchored in the organisation, stakeholders must be properly involved in the planning process. An organising team should be appointed by the top management and given responsibility for planning and conducting the risk assessments. If the risk assessment is performed at a fish farm, the operational manager should be responsible. The safety representative elected by the employees, a duty statutory in the Working Environment Act (Norwegian Ministry of Labour and Social Affairs, 2005), should also be involved. It is necessary to have personnel experienced with risk assessments in the group, e.g. HSE personnel. The group shall define problems and the scope of the work and specify which types of risk are to be assessed. The group should also decide on a method for hazard identification and risk analysis, and this should be suitable for the data sources available, system/object and risk type to be analysed. If a template for risk assessment is used, feasibility must be assessed, and if necessary, revised.

4.1.2 Risk analysis

Current practice for the risk analysis step is close to the requirements of the standard, as is to be expected because it is usually regarded as the "core" of the risk assessment process. The documentation of risk assessments is largely based on this step. One necessary improvement is to identify hazards and undesired events associated with the various tasks that make up an operation, including the use of equipment. Implemented risk-reduction measures must be taken into consideration. Today's prevailing practice is to pick these out from a template or to list hazards and undesired events without the operational context, which in itself might influence the risk level. A template should only be used as a checklist for possible hazards or undesired events, as well as for possible actions to mitigate risks.

4.1.3 Risk evaluation

The evaluation against risk acceptance criteria need not be a central task for the entire work group, as in practice it might end up as a mere "exercise" to avoid "red" entries in the risk matrix. The organising team, and/or HSE personnel, may finalise this step. The contribution of operators should be aimed at identifying additional safety barriers and other mitigating measures in order to reduce the likelihood or consequences of high risks, as well as prioritisation of measures. This task should be prioritised when limited time is available for gathering all the personnel involved. Operator participation in this step can be ensured by involving the safety representative or another person representing the operational staff. In many cases, the operations manager has considerable experience with the operations, as he/she has often started working as an operator. Table 5 is a stepwise summary of the suggested improved approach for risk assessments in the industry. NS 5814 should be used as a reference. The following section describes the testing of this approach at four workshops.

Table 5 Stepwise specification of the suggested improved approach for risk assessments in the fish farming industry. The suggested process aims to close the gaps identified between current practice and the requirements in NS 5814 (Standard Norway, 2008).

	Improved approach	Comment
Planning		
A	Establish an organising team appointed by the company management.	Include HSE personnel with training in risk assessments, who will be responsible for documentation. The farm operational manager is responsible, and the safety representative should be involved.
B	Identify work operation(s) of high risk.	Should be based on operational experience and incident reports.
C	Decide which type(s) of risk to assess. a. If applicable, assess and revise template. b. Choose a suitable method for risk analysis according to the type of risk to be assessed.	Should be specified in company risk management procedure; e.g. fish welfare, HSE, food safety (see Table 4).
D	Gather a group of operators and managers responsible for performing the operations.	Workshop with operators: Mix fish farmers and service vessel crews if possible and relevant for the operations involved.
E	Describe operations at individual task level, including critical gear/equipment used. Agree on safe job practices.	HSE personnel should update the written work procedure if deviations are identified and justified.
Risk analysis		
F	Identify hazards and undesired events associated with each task/equipment.	Workshop with operators.
G	Analyse causes and likelihoods for each hazard/event, taking existing risk-reducing measures into consideration. Analyse consequences.	Workshop with operators.
H	Describe risks in terms of product of potential consequences and likelihood.	Organising team may perform this step.
Risk evaluation		
I	Evaluate risks against risk acceptance criteria.	Organising team may perform this step.
J	Identify additional mitigating measures to be taken and evaluate their risk-reducing effect.	Mitigating measures should be discussed at workshop. The organising team may perform the evaluation of risk-reducing effects.
K	Document risk assessment process.	HSE personnel.

4.2 Testing and evaluation of the approach: workshops

The improved approach outlined above was tested and evaluated in four workshops with industry participants. The practical organisation of the workshops have previously been described in detail by Holmen et al. (2017c). The steps of the NS 5814 risk-assessment process were followed, and the process was organised as shown in Table 6.

Table 6 The involvement of personnel in the risk assessment process.

Step in NS 5814 (Standard Norway, 2008)	Organising team	Workshop (operators, HSEQ staff and managers)	HSEQ staff
Planning			
• Initiate process, define problem and scope	X		
• Organise the work, establish work group	X		
• Choose method and data sources	X		
• Establish description of system and object to be analysed, document conditions and assumptions		X	
Risk analysis			
• Identify hazards and undesired events		X	
• Analyse causes and likelihoods		X	
• Analyse consequences		X	
• Describe risk as a product of potential consequences and likelihood	X	(X)	(X)
Risk evaluation			
• Evaluate risks against risk acceptance criteria	X	(X)	(X)
• Identify mitigation measures, compare alternatives and their risk-reducing effect		X	
• Document and conclude	X		(X)

Table 7 (adapted from Holmen et al. (2017c)) lists the number and category of participants in each of the workshops, as well as the service vessel operations that were the topics of each workshop. These operations were identified as being of high operational risk, based on current analyses of occupational accidents and fish escapes, as well as the participants' own experience and perception of hazards. All these operations involve the use of winch and/or cranes. In workshop 3 it was decided to analyse "preparations for fish transfer" and "maintenance operations", which include several of the other operations. Lifting of coupling plates precedes anchor setting and/or tightening of moorings. Delousing involves lifting of the sinker tube, which is also an initial stage in the preparations for fish transfer. No templates were used in any of the workshops. The risk analysis method in the workshops was based on the preliminary hazard analysis described by Rausand and Utne (2009). The focus for hazard identification was limited to risks to personnel and escape of fish.

Table 7 Work operations for risk assessments discussed in the workshops, including number and category of participants: Managers (M), fish farmers (F), service vessel crew (S), technology providers (T).

Workshop no.: Participants: No. of participants: ↓Operations	1 M F S 20	2 M F S 17	3 M F S T 12	4 M F S T 13
Clean floating collars				
Tighten moorings				

Set and fasten anchors in seabed				
Swim fish between net cages				
Mount nets in cages				
Lift coupling plates				
Preparations for fish transfer				
Maintenance operations				
Lift sinker tube				
Remove old moorings				

The above activities cover steps A-C in Table 5. The next step was to gather operators and managers to do the risk analyses. Up to four operations were analysed per workshop (Table 7). To do this efficiently, the participants were divided into groups, each of which described one operation. The groups were initially placed at separate tables (Holmen et al., 2017c). After a while, the groups rotated to the next table and added information to the description by the previous group. The work operations (object of analysis) were thus described in detail by all the participants, and a thorough description of the work tasks and involved objects/tools was produced. The results showed that while the operations usually were performed in accordance with the written procedures, a few major discrepancies at certain stages were also revealed. These were dealt with as a part of the following risk analysis process.

The second assignment for the groups was to identify hazards and undesired events associated with each operation described above (step F in Table 5). Again, each group started on one operation, and rotated to the next table until all the operations had been analysed. This was repeated for the analysis of causes, likelihoods and consequences, and identification of mitigation measures (step G). Steps G-J were finalised in workshops 1 and 2, but were not fully tested in workshops 3 and 4. In these workshops, each hazard/undesired event, possible causes and consequences were assessed qualitatively. The priority in the workshops was to establish thorough descriptions of the operations, and to identify hazards and undesired events associated with each task of the operation. The operators were involved throughout the process of listing existing safety barriers/measures and suggesting further risk-reduction measures, as this also increased their understanding of how safety can be improved in their daily work. The organising team documented the process (step K).

5 RESULTS AND DISCUSSION

5.1 CURRENT PRACTICES FOR RISK ASSESSMENTS

5.1.1 Implementation challenges

The aquaculture industry is obliged to perform and document risk assessments in accordance with the legal framework presented in Table 1. Complying with requirements from five authorities is a time-consuming and resource-intensive task. The priorities of the companies involved in the interviews and workshops were found to be affected by possible damage to the profits or the reputation of the industry. The media's often negative attitudes to the fish farming industry has been shown not only to influence the public, but also to limit the regulatory focus on sustainability to environmental risks (Olsen and Osmundsen, 2017). The present study shows that most efforts are put into the documentation of actions to mitigate environmental hazards, i.e., fish escapes.

Several challenges were identified regarding current risk assessment performance. First, the companies find it difficult to allocate sufficient time to gather all relevant personnel for risk assessments. As a result, at some fish farms this may be done only at managerial level. Second, some of the participants lack motivation and see it as an unavoidable "exercise" to satisfy the demands of the authorities or their own management. Third, finalising the risk documentation is regarded as more important than checking whether the significant risks are understood and mitigated. Fourth, the scope of the risk assessments is broad. It may take several days to perform assessments of all types of risk as regulated by the authorities. Any prioritisation is affected by public opinion and consumers' concerns, and possible sanctions by the authorities. Fifth, once the risk assessments have been finalised, the follow-up work with detailing of action plans and improvements of procedures may not be prioritised, giving the wrong signal back to the organisation that the only point of the risk assessments is to satisfy the documentation requirements in the regulations. These challenges are further addressed in the following sections.

5.1.2 Variable quality and content

The information that we gathered through interviews and observations shows that the quality and implementation level of risk assessments vary considerably, between both companies and different sites run by the same company. Some companies, typically the larger ones with well-established safety management functions and trained staff to maintain the systems, have implemented computer-based, online systems for quality and safety management, and have written procedures on how to perform risk assessments, specifying the types of risk that are to be included. The smaller companies are, so far, less systematic in documenting the activities required of them. There are also observations that suggest a lower level of implementation on board service vessels than at fish farms. Several of our informants had not personally been involved in the risk-assessment process, and work was still under way to complete the risk assessments for some vessels. The vessel operators explain that this is because they have less time available for safety management on board. The operations managers at the fish farms also have more predictable working hours, in some cases more or less "fixed" office hours, and have access to an office and to online quality-management systems. Service providers are experiencing a growing demand from fish farming companies to document work operations and compliance with safety requirements, and this is likely to be a driving force for subcontractors to the fish farming companies to implement systematic risk management and risk assessments.

The risk assessments that we studied without exception are semi-quantitative and are described in risk matrices. These are known to have limitations, as they are mainly based on subjective assessments that depend on individual experiences (Cox, 2008). Public reports on fatalities, serious occupational injuries and fish escape may be used as qualitative input to the assessments. As an easy tool to visualise and document the outcome of the hazards identification and risk analysis process, risk matrices serve their purpose for aquaculture companies, as long as they understand their limitations.

5.1.3 Level of implementation

A recent survey of safety management practices among management and office staff in the Norwegian aquaculture industry investigated several aspects of safety management implementation (Kongsvik et al., 2018). A total of 135 persons from 15 companies participated in a web-based survey, and risk assessment and SJA was among the topics. For example, the following question was asked; "Have formal risk assessments for the work at the fish farm been carried out during the past four years?" As many as 98% of the respondents responded positively to this, and 86% reported that all employees participate in the risk assessments, while 81% said that risk assessments are actively employed to reduce occupational risks. These numbers are relatively high compared to the feedback from the participants in the qualitative study described here. However, the survey was aimed at managerial level, and the answers might well have been different if the operator level had been asked the same questions.

The situation in the aquaculture industry regarding the risk of occupational injury does seem to be improving (Holen et al., 2017a), as well as fish escape. Escapes of farmed fish have significantly diminished since 2006 (Directorate of Fisheries, 2017b). The major cause of fish escapes is holes in the net (Føre and Thorvaldsen, 2017), which indicates that risk assessments should be focused around events which lead to tearing of nets. One explanation for the reduction in escapes is that the authorities have improved their inspection routines. Another is that the industry, which is rapidly growing, needs to improve its reputation in order to recruit qualified workers. This increases the motivation for top management to allocate sufficient resources to risk management. According to industry representatives, a fewer incidents happen during complex operations than before, and this is explained by improved routines for planning and comprehensive risk assessments. However, the safety management survey showed that there still is room for improvement (Kongsvik et al., 2018).

Compared to other ocean industries such as the offshore petroleum sector, safety management systems in fish farming are not yet as comprehensive (Holmen and Thorvaldsen, 2015). Fewer resources are allocated and motivation for performing paper-work is low. A more practical approach to improving the impact of risk assessments, and in turn risk management, would therefore be beneficial for this industry.

5.2 Closing the gaps

The following section, "Improved approach to risk assessments", discusses improvements regarding operator involvement and hazard identification. Planning, time and resource allocation are addressed in the section "Limited resources require efficiency and good planning" (5.2.2). Different aspects of documentation are discussed in all sections. Templates are specifically addressed in "Additional recommendations" (5.2.3).

5.2.1 Improved approach to risk assessments

The intention of the risk assessment process is to systematically gain a greater understanding of the risk situation in the work environment. The operational staff have the practical experience, and they daily face the hazards and make decisions to prevent accidents from happening. As the improved approach recommends, their involvement should start at the stage where the system is described, by mapping the stages in the operations, which they know well, and thereafter by identifying the hazards associated with each stage. Causes and consequences should also be discussed in groups that include operators, managers and HSEQ staff. Thus, if the managers follow up by documenting the process and establishing a shared action plan for risk-reducing measures, an important part of the regulatory internal control will have been implemented (Norwegian Ministry of Labour and Social Affairs, 1996).

The process of describing risks and evaluating them against risk acceptance criteria can be finalised by the operational management supported by HSEQ personnel. Decisions on which preventive measures to prioritise are closely connected to budget discussions at management level, and the suggested approach will ensure that the management is familiar with levels of risk in the workplace. In audits or accident investigations, the risk assessments are used by the authorities as a quality indicator of the risk management. They will also record which risk-reducing measures the company has identified and perhaps implemented. It is therefore essential that companies can document that they have performed thorough risk assessments as the basis for mitigating risks inherent in the work environment on vessels and at fish farms.

The workshops (Holmen et al., 2017c) produced detailed descriptions and risk assessments of work operations and equipment, as well as a list of preventive and risk-reducing measures. A common understanding of the work environments and operations was established between the operators and managers. An example is how the coupling plate should be lifted out of the sea. The correct way to do this is to attach the crane to the chain which connects the buoy to the coupling plate, and not lift the buoy itself, unless the buoy is certified for lifting. The added hazards of this irregular procedure were thoroughly discussed. Differences in procedures might also be explained by the kind of equipment that is available at each fish farm. Participants appreciated having the opportunity to exchange their experiences across regions and companies. This was an added value of the new approach. Industry associations may take this further and develop industry standards for risk assessments and knowledge sharing. The Norwegian construction industry is a good example of this, as it has already developed a collective standard for risk assessments of construction work; NS 5815 (Standard Norway, 2006).

The most important improvement due to the approach presented in this paper, compared to established practices, is the strong involvement of the operators. This is a requirement described in the internal control regulation. The use of group discussions and of documenting input on flip-over sheets lowers the threshold for contributions from everyone. Furthermore, the focus is shifted from lowering the RPN to acceptable levels, towards a shared understanding of the need for measures that can eliminate hazards or reduce the consequences of any incidents that do occur. This approach thus supports the overall goal of the required risk assessments, which is to identify means of reducing risk to fish welfare, food safety, and technical and personnel safety at aquaculture workplaces. These risk assessments can thus also be used as a tool for operational planning, as well as a basis for safe job-analysis checklists.

Furthermore, the organisation of the workshop, with several groups providing input to the different operations in turns, resulted in more comprehensive recordings of the hazards than any group would have produced on its own. This can be achieved in a company by gathering operators from several fish farms and/or service vessels. This will also be an arena for organisational learning, as the operators can exchange experience and knowledge regarding safe and efficient job practices. Finally, it is likely that needs and ideas for improved engineering solutions that eliminates hazards are identified. The results of systematic risk assessments are thus of high interest also to manufacturers of equipment. This was demonstrated when technology providers were invited to two of the four workshops (Holmen et al., 2017c).

5.2.2 Limited resources require efficiency and good planning

The greatest challenge to performing high-quality risk assessments is probably that of allocating enough time to involve the operators sufficiently according to the Internal Control Regulation (Norwegian Ministry of Labour and Social Affairs, 1996) and NS 5814 (Standard Norway, 2008). Competent and committed managers are required in order to involve the operators properly. Qualified

HSEQ staff should ideally be of support to the operational managers during the risk assessment process and be a driving force in the organising team. The larger companies usually have such personnel available who could relieve the operational manager from some of the planning activities. In the smaller companies, several management functions may be gathered on one person, thus making it hard to allocate time for a proper risk assessment involving the operators. The suggested improved approach is not less time-consuming; however, it can increase the efficiency of the process in that a more comprehensive list of risks and mitigation measures are documented. Furthermore, the learning outcome of the process is likely to be greater because each operation and its inherent hazards are analysed in detail: a common best practice is put in writing, the operators take part in the identification and description of causes, consequences, likelihoods, risks, risk-mitigating measures and evaluation of their effect.

During the fish production phase, which lasts for approximately 18 months, there are few available time windows for this resource-intensive work. Usually there are two teams at each fish farm working shifts, although only one operational manager and at some farms, a deputy manager. One strategy could be to treat risk assessment efforts as a mandatory seminar and bring the off-duty team together away from the fish farm for a couple of days. This can be done at intervals until all relevant operations and components have been analysed. However, this may come in conflict with the Working Environment Act's regulations on the maximum permitted working hours per week and month (Norwegian Ministry of Labour and Social Affairs, 2005). The work shifts at fish farms are already carefully tuned to be in line with the requirements (Thorvaldsen et al., 2017).

Another strategy would be to allocate time for updating risk assessments between fish generations, which is normally a period of two or three months. However, during this period of no fish to farm, major maintenance activities to prepare for the new stock are scheduled, and the focus is therefore on the technical aspects of planning the next production cycle. The risk assessments are the basis for an efficient risk management both at the fish farm as well as in the company. Ideally, the company management should plan the production cycles so that the fish farm personnel are also given sufficient time to update the risk assessments.

5.2.3 Additional recommendations

Several of the companies that participated in this study have designed templates which are adapted to each vessel or farm. Using a template can increase the effectiveness of the risk assessment process, since possible hazards, causes and consequences are already listed for different systems and the template serves as a checklist. Regular updates based on the outputs of risk assessments performed as recommended in this paper will improve both the content and the impact of the templates. A thorough template based on best operating practice could simplify risk assessment updates for complex operations, e.g. when new technology or maintenance schedules are implemented, or a new crew joins a vessel.

The use of safe job analysis (SJA) has increased during the past few years, as it is recognised that this is a useful tool for a carrying out systematic risk analysis in operations, i.e. stepwise mapping of hazards, causes, consequences and risk-reducing measures associated with a given work task or operation. However, at present, there are probably as many versions of how to perform SJA, both in content and template for documentation, as there are aquaculture companies. The petroleum industry has introduced recommended guidelines for SJA (Norwegian Oil and Gas Association, 2017). These guidelines describe step by step how to conduct SJA, and could be adapted for use in the aquaculture industry to establish a common procedure. An SJA performed as described in these guidelines would to largely satisfy the requirements in the planning and risk analysis steps of the risk assessment process described in NS 5814. SJA is therefore a suitable methodology for risk assessment of operations (see step C in Table 5).

As section 2 mentioned, the regulatory requirements for risk assessments are fragmented, as they are statutory instrument promulgated by five different authorities (Holmen et al., 2017c). Risk management is therefore dealt with in separate parts of company management systems. These are also audited separately, although the Directorate of Fisheries and the Food Safety Authority coordinate inspections because they are regulatory authorities for separate parts of aquaculture legislation (Table 1). Yang et al. suggest that five dimensions of risk should be considered in a single risk-management system; risk to personnel, risk to material assets, risk to fish welfare, risk to the environment and food safety. There is thus a potential for merging the requirements of the individual sets of regulations into a unified management system. The aquaculture industry should be encouraged to establish common regulations and guidelines for a holistic risk-management system, which would combine all relevant types of risk.

6 CONCLUSIONS

This paper describes and discusses the implementation of risk assessments in the Norwegian aquaculture industry, and compares the current practice with the recommendations in the Norwegian standard NS 5814 (Standard Norway, 2008). An improved approach to risk assessment was suggested and evaluated.

Previous studies show that the Norwegian aquaculture industry has safety challenges which could be mitigated by systematic risk management, of which risk assessment is a core activity. An aquaculture industry standard for risk management across the regulatory disciplines is lacking, while other sets of regulations may include safety requirements that address similar objectives. This results in a fragmented approach to risk assessments. Practices for risk assessments differ greatly between companies in the Norwegian aquaculture industry. There is therefore a potential for making significant improvements to the situation by implementing a systematic and standardised approach to risk assessments.

The comparison between the recommended steps for risk assessments in NS 5814 and current practice found the largest gaps in the planning phase, and regarding the obligatory involvement of workers in the risk analysis phase. Operator involvement was often either inadequate or missing. Furthermore, the link between operations as a source of risk and risk assessments was not clear, especially if the template did not support the breakdown of operations into tasks. Finally, documentation was unsatisfactory according to the requirements in the standard.

We developed and tested an improved approach to risk assessment based on preliminary hazard analysis in cooperation with the aquaculture industry (Holmen et al., 2017c). The largest difference compared to current is that our approach describes each operation in detail, assesses the hazards, describes and evaluates the risks associated with each task, instead of merely listing general hazards and assigning risk levels to them. Hazards associated with known high-risk operations as cranes and winches were thus described in the relevant context. This approach will increase the likelihood for identifying possible new hazards arising if the lifting operation is changed or if the crane is used in a new setting. This approach has been tested and evaluated in a series of workshop and demonstrated a high level of involvement by the operators. The outcome of the process was not merely a comprehensive list of hazards and mitigating actions. According to the operators, they appreciated the opportunity to discuss best practices with colleagues and operators across regions and companies. Thus, the improved approach as described in this paper also contributed to an improved common understanding of how operations should be performed with safety in mind.

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