The status of risk assessments in Norwegian fish farming

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ABSTRACT: The oceans will become the major contributor to the needed increase in global food production towards 2050. The fish farming industry is characterised by operations that are susceptible to changing weather, wind and currents, and face challenges when it comes to safety for fish and personnel. Previous research and accident analyses reveal a lack of understanding of risk factors during aquaculture operations. The objective of the paper is primarily to describe the status for risk assessments practices in the Norwegian fish farming industry according to the regulatory requirements. To improve the safety level at workplaces, the operators need to be aware of the safety challenges in their working environment. A practical approach to risk assessments based on preliminary hazard analysis is presented in this paper. This approach has been developed in cooperation with the aquaculture industry and has been evaluated in a series of workshops involving several operators with good results.

1 INTRODUCTION

Due to a growing population on our planet, the world's food demand is estimated to increase by 69% towards 2050. The oceans will become the major contributor to the increase in global food production (World Resources Institute 2013). Furthermore, marine oils are already in short supply, since both the health food industry and the producers of fish food have an increasing demand for this essential ingredient. Thus, a higher volume of marine oils also has to be produced and harvested from the oceans (Carvajal et al. 2015). Because of the growing market for seafood and biomarine ingredients, the Norwegian fish farming industry is expected to grow fivefold within year 2050 (Olafsen et al. 2012). Locations for the increasing biomass production in Norway are sought in more remote and exposed waters (Bjelland et al. 2015). This implies a need for the development of new technology, concepts and management strategies that meet the requirements for production in harsher environments. An important task in the concept engineering process is to evaluate how risks related to health, safety, and the environment (HSE) in aquaculture can be reduced by implementing new strategies for fish farm operations, including autonomous systems and integrated operations (Utne et al. 2015).

Today's fish farms already face challenges when it comes to safety for fish and personnel. Operators in the Norwegian aquaculture industry have the second most dangerous profession in terms of occupational accident rate (Aasjord & Holmen 2009, Holen et al. 2016a). Since 2005, eight fatal accidents in Norwegian aquaculture have occurred (SINTEF Ocean 2017). Operations involving cranes or winches are the major contributors to these accidents (Holen et al. 2016b), of which many are performed as part of work-demanding delousing procedures. Lice are parasites that pose a hazard to the fish welfare, as well as the delousing process to remove them. The companies will be fined if violations against the Fish Welfare Act is revealed (Food Safety Authority Norway 2017a), and strict regimes to monitor fish welfare and conduct delousing are decreed (The Norwegian Ministry of Trade, Industry and Fisheries 2012, Food Safety Authority Norway 2017b).

Present delousing techniques implies an increased risk for occupational injuries and for escape of fish. Actions were taken during the beginning of this millennium to mitigate the increasing numbers of escaped fish due to structural breakdowns or technological failures (Jensen et al. 2010). Operational errors and structural deficiencies due to insufficient or missing safety barriers are now the prevailing causes for fish escape (Directorate of Fisheries 2016).

Research is ongoing to develop fish farm concepts that will reduce infestation by sea lice and thus prevent the risks associated with delousing operations. However, chemical and mechanical methods are still dominating (Stien et al. 2016). Both the welfare of the fish and the industry's reputation are threatened by escapes, and the operators admit that personal safety may be compromised to prevent an accident (Størkersen 2012). Thus, the "human factor" can be pointed to as a safety factor in fish farming (Thorvaldsen et al. 2015). Knowledge about this is important to understand the elements of the risk picture in the aquaculture industry. A preliminary study by Holmen & Thorvaldsen (2015) showed that the aquaculture industry is behind comparable industries with respect to implementing systematic risk management.

Risk management is the continuous process of identifying, analysing, planning, tracking and controlling risks (ISO 2009, Rausand 2011). Risk assessment is an essential part of risk management because it supports decisions by analysing and evaluating risk, and prioritisation of risk reducing measures for design and operation. The goal of risk management is to implement measures to prevent identified hazards or reduce the consequence of undesirable events (Aven and Vinnem 2007). This concerns the health and safety of workers or people in general, as well as the environment, property and other assets.

Previous research and accident analyses reveal a lack of understanding of risk factors during marine operations in aquaculture (Jensen et al. 2010, Holen et al. 2014, Thorvaldsen et al. 2015, Holen et al. 2016a, Holen et al. 2016b, Holmen et al. 2017a, Holmen et al. 2017b). Two investigation reports on fatal marine accidents (AIBN 2014, AIBN 2015), both point to the fact that inadequate competence (training) and risk management were major contributors to the accidents. The fish farming industry is characterised by operations that are susceptible to changing weather, wind and currents, which affect the availability of the fish farms. Fish welfare is dependent on regular feeding and prevention of diseases and parasites. In this context, the experience and skills of the fish farmers are important organisational safety barriers. Inadequate training thus seems to be a risk factor in itself.

The fish farming industry is thus likely to benefit from improved risk management. A starting point could be to implement improved strategies for thorough assessments of operational risks as a basis for developing effective preventive measures. Operating personnel need to be involved in the risk assessments to increase the individual awareness of risks inherent in daily work. This is also a regulatory requirement (Norwegian Ministry of Labour and Social Affairs 1996). The aim is to ensure that relevant workplace hazards are identified and understood by those actually performing the work, and to facilitate development of adequate preventive measures.

The objective of the paper is to describe the status for risk assessment requirements and practices in the Norwegian fish farming industry. Additionally, the paper suggests an improved practice for the risk assessments, compared to how many aquaculture companies perform them today.

2 METHOD

2.1 *Risk assessment*

Some sectors in Norway have their own regulations on how to perform risk assessments, or it is required that they follow a certain international or national standard. The aquaculture sector does not have an industry standard for risk management. The Norwegian standard NS5814 (Standard Norway 2008) describes requirements to risk assessments and for industries in general. Some regulations in the aquaculture sector refer to this particular standard; otherwise, it is voluntary to implement it. There are examples of individual companies that have internal requirements linked to NS5814. It is mandatory to perform and document risk assessments for all aquaculture operations, as well as the activities related to breeding and farming fish and keeping them healthy.

The risk assessment process used in this paper is based on the approach in NS5814:

I. Planning
   a. Initiate process, define problem and scope
   b. Organise the work, establish work group
   c. Choose method and data sources
   d. Establish description of system and object to be analysed, document conditions and assumptions

II. Risk analysis
   a. Identify hazards and undesired events
   b. Analyse causes and probabilities
   c. Analyse consequences
   d. Describe risk as a correlation between consequence and probability

III. Risk evaluation
   a. Evaluate risks against risk acceptance criteria
   b. Identify mitigating measures, compare alternatives and their risk-reducing effect
   c. Document in writing and conclude

2.2 *Data collection*

The methodological approach in this paper includes data collection from several information sources. Relevant standards, laws and regulations have been searched for relevant regulatory requirements on risk assessments. The requirements are summarised in the next section. Interviews and observations have been conducted during service operations at fish farms. During the visits, samples of the documentation in the safety management systems were checked. The information gathered through the interviews and observations gave an overview of current practices, deficiencies and needs for improved risk assessment in aquaculture. Based on this knowledge, an alternative approach to conduct risk assessment tailor-made for aquaculture was developed and tested during four workshops.

The information from participants in interviews and workshops have been treated anonymously and has been handled according to the principles of the Norwegian Data Protection Official for Research.

2.2.1 *Interviews and observations*

Interviews were conducted with managers, HSEQ (health, safety, environment and quality) personnel and operators in six Norwegian aquaculture companies regarding practices for risk assessments. Informants from both fish farming companies, in-house service vessels and subcontracting service providers were included. Nine individual interviews were carried out at the workplace of the operators. Eight interviews were conducted with HSEQ representatives in the companies. Furthermore, meetings were arranged with two management groups and questions regarding HSE policies were asked. The interviews were semi-structured (Bernard 2006) and performed either in person or by phone.

In addition, observations were conducted on board four service vessels performing maintenance operations on fish farm structures and moorings. One of the service vessels were hired, the other three were owned and operated by one of the fish farming companies. The crew of the service vessels were two or three operators, depending on the range of use for the particular vessel. The operators on board the vessels were asked to demonstrate and explain work practices and risk treatment in daily operations.

The purpose of the interviews and fieldwork was to audit the risk assessment practices, and how these were used in the daily work on board. The questions asked were adapted according to the responsibility associated with the informant's formal position in the company. The HSEQ personnel were primarily asked questions on the system level, procedures for risk management and documentation of the practical applications.

2.2.2 *Workshops*

Four workshops were arranged in December 2015, March and April 2016, with managers, fish farmers and service vessel operators. Some of the interview objects were also participants in one or two of the workshops. Providers of aquaculture technology were invited to the latter two, to explore the potential for integrating risk-reducing measures, or safety barriers, in the design of technology concepts. Risk assessments for several service vessel operations were performed. The operations were identified to be of high risk based on current analyses of causalities in occupational accidents and fish escapes, in addition to the participants' own experiences. Table 1 presents the work operations that were risk assessed, and the number of participants and their expertise.

The general process in NS5814 were followed. The planning of the risk assessments was carried out by the organising team beforehand, except that the work operations were described by the participants. For the first two workshops, the organising team consisted of two researchers and one HSEQ coordinator from one of the fish farming companies. Three more researchers and a representative from the industry participated in the preparations for the next two workshops.

Table 1. Description of workshops. Work operations for risk assessments, number and category of participants are shown.

Workshop no.	1	2	3	4
Participants*	M F S	M F S	M F S T	M F S T
No. of participants	20	17	12	13
↓Operations				
Cleaning of floaters	x			
Tightening of moorings	x			x
Set and fasten anchors in seabed	x	x		
Swim fish between net cages		x		
Mount nets in cages		x		
Lift coupling plates	x	x		
Preparations for fish transfer			x	
Maintenance operations			x	
Lifting sinker tube				x
Removal of old moorings				x

*Participant categories: Managers (M), fish farmers (F), service vessel crew (S), technology providers (T).

3 RISK ASSESSMENTS IN NORWEGIAN AQUACULTURE

3.1 Regulatory requirements

The fish farming industry in Norway has to report to five different regulatory authorities regarding safety management. These are the Directorate of Fisheries, Food Safety Authority, Norwegian Maritime Authority, Norwegian Labour and Inspection Agency and the County Administration. These bodies have the supervision for fish welfare, food safety, fish farm technical standard, vessel design and equipment, HSE. The safety management requirements are described in more detail by Holmen et al. (2017a). This Section summarises the legal framework for risk assessments in the different regulations.

3.1.1 *Fish welfare and food safety*

The aquaculture legislation and regulations place legal responsibilities on the companies and the operators regarding risk management and control. The purpose of the Aquaculture Act (Norwegian Ministry of Trade and Fisheries 2005) is to facilitate the aquaculture industry's profitability and competitive ability within the frames of sustainability. The Regulation on internal control to comply with aquaculture legislation, IK Aqua (Norwegian Ministry of Trade and Fisheries 2004) states that the companies have to document systematic measures to show compliance with the aquaculture legislation: Assessments of risks, mitigating measure, plans and actions to reduce risk. The Directorate of Fisheries and The Food Safety Authority are both regulatory authorities for the IK Aqua, but within separate areas. This is explained further in the next paragraphs.

The Regulation on the operation of aquaculture production sites (Norwegian Ministry of Trade and Fisheries 2008) is statutory in the Aquaculture Act and aims to support technical, biological and environmentally sound production. Risk assessments must be conducted to minimise the risk of fish escapes and implement systematic preventive measures. The regulatory authority for this part is the Directorate of Fisheries. The same regulation also contains clauses concerning fish health and welfare, controlled by the Food Safety Authority. These requirements are linked to the Food Act and the Animal Welfare Act. Risk assessments shall be performed for health control parameters and water quality. The follow-up of these requirements should be included in the internal control system of the company.

3.1.2 *Technical regulations for aquaculture structures and vessels*

The Fisheries Directorate is the controlling authority for the technical requirements of the components of a fish farm. The technical state of fish farms shall comply with the requirements in the Norwegian standard NS9415: Marine fish farms - Requirements for site survey, risk analyses, design, dimensioning, production, installation and operation (Standard Norway, 2009). This standard refers to NS5814 (Standard Norway 2008) for risk assessments.

The "Regulation on technical requirements to floating aquaculture installations" (Norwegian Ministry of Trade and Fisheries, 2011) was introduced to ensure compliance with NS9415. A site survey and assessments of component and mooring design and dimensions, are to be performed and approved prior to the establishment of the fish farm.

A regulation for cargo vessels of 8-24 meters length was enforced by the Norwegian Maritime Authority in 2015 (Norwegian Ministry of Trade, Industry and Fisheries 2014). This regulation introduced new technical requirements for the aquaculture fleet below 24 meters. The Maritime Authority thus became the regulatory authority for the service vessels. One of the requirements is to have the vessel stability tested, so that the safe load margins are known to the crew. Several accidents have happened due to errors in lofting or loading operations compromising the stability of the vessel. The service vessels are an important tool in several fish farm operations and shall thus be included in the risk assessments of such operations.

The working environment for the crews are, however, still under the supervision of the Norwegian Labour and Inspection Agency (NLIA).

3.1.3 *Health, safety and environment (HSE)*

All workers are entitled to have a safe and sound working environment and this right is sanctioned by the Working Environment Act (Norwegian Ministry of Labour and Social Affairs 2005). Several regulations detailing requirements to, e.g., workplace safety, machines and tools, organisation and involvement and internal control are linked to the Working Environment Act.

Figure 1. The steps of the Internal Control mandatory for the Norwegian aquaculture industry (adapted from NLIA 2017b).

The internal control regulations on health, safety and environment (HSE) (Norwegian Ministry of Labour and Social Affairs 1996) decrees the enterprises to document compliance with the working environment laws and regulations. One of the mandatory tasks is to conduct and document risk assessments and plans for implementing risk-reducing actions. This shall be carried out for all physical, chemical and biological, organisational, psychosocial and ergonomic elements of the working environment. This includes a range of fish farm and service operations, work procedures, as well as tools and equipment used. Furthermore, it is stated that employees shall be trained to be active contributors in this work. The Norwegian Labour and Inspection Agency (NLIA) checks the documentation of this work during audits (NLIA 2017a). Figure 1 shows the steps of the Internal Control loop (NLIA 2017b).

The environmental part of the Working Environment Act, i.e., risk assessments of the sustainability of the aquaculture location and emissions to the surrounding environment, is controlled by the County Administration.

3.2 Practices for risk assessments in Norwegian aquaculture

The aquaculture companies aim to comply with the legal framework presented in the previous Section. The present regime of complying with requirements audited by five authorities is time-consuming and resource demanding. The priorities of the companies involved in the interviews and workshops were found to be affected by possible harms for the profit or the reputation of the industry. A recent study concludes that media's negative publicity of the fish farming industry influences not only the public, but also constricts the regulatory focus on sustainability to environmental risks (Olsen & Osmundsen 2017). Furthermore, a general industry standard for a holistic risk management across the regulatory disciplines is lacking, and safety requirements concerning similar objectives are found in separate regulations. This results in a fragmented approach to risk management, and most work are put into the documentation of actions to mitigate environmental hazards, i.e., fish escapes.

The interviews and observations show that the quality and implementation level of risk management vary considerably, between both companies and different geographical locations within the same company. Some companies have written procedures on how to do risk assessments, specifying the range of areas to be included, and have online systems for documenting internal control activities. Other companies struggle to find time to do risk assessments, as required. Several of the informants had not been personally involved in the process, and work was still going on to complete the risk assessments for some of the vessels. The service providers experience an increasing demand from the fish farming companies to document work operations and compliance with safety requirements.

Fish farmers and service vessel crews assess weather conditions and other factors influencing safe operations during work, however, these are not documented. The crews are given the authority by their managers to delay or abort operations, because the situation may change rapidly. It requires a certain degree of competence to execute this authority and to make the right decisions. There are no formal stop criteria, thus solely dependent on the expertise of the operational manager.

The requirements for risk analyses in NS5814 do not specify whether they shall be quantitative or qualitative. Qualitative risk analyses using risk matrixes prevail, in fact no quantitative risk analyses have been presented to the researchers. It is usual to describe risk as the product of consequence and probability. The result is evaluated against risk acceptance criteria expressed by the colours green (low risk - no further action needed), yellow (medium risk – consider additional safety measures) or red (high risk – risk-reducing measures to be implemented immediately). The risk acceptance criteria is decided by the management, based on a suggestion made by HSEQ personnel. One of the companies in this study conducts risk assessments along seven dimensions: Fish escape, health and safety for humans, surrounding environment, fish welfare, fish health, food safety, food threats. A 5x5 risk matrix is often used to illustrate the total risk picture.

The fish farming companies should perform risk assessments in several areas. It can be resource demanding to keep track of the hazards recorded for each area. The follow-up and risk treatment activities is a considerable job and raise the need for a computerised systems to keep track of the follow up actions. It is common to use spreadsheets in MS Excel to record and process inputs to the risk assessments. This program is well known and has the flexibility to insert extra columns and rows when needed. There are also several commercial computer-based risk assessment systems available, and some of the companies have – or are about to - implement such tools.

Several challenges were identified regarding risk assessment performance: first, the companies may have difficulties in finding time to gather all relevant personnel who should participate in the analyses. At some fish farms, risk assessments are performed at manager level only. Secondly, some of the participants are not motivated for the task as they see it as an unavoidable "exercise" to satisfy the demands from the authorities or their own management. Third, those requiring the risk documentation are more concerned about text and numbers in all columns of the risk assessment form than to check whether the safety level is acceptable. Fourth, the scope of the risk assessments is too broad, and it may take several days to perform risk assessments of all relevant parts of the fish farming. Some operations could then be omitted due to limited time. Fifth, when the risk assessments are finalised, the follow-up work with detailing of action plans and improvements of procedures are not prioritised. This may give the wrong signal back into the organisation that the only use of the risk assessments is to satisfy the documentation requirements in the regulations.

3.2.1 *"A cup of coffee chat"*

In the ideal world, the identified risks would be the input to safe job analyses (SJA) prior to complex operations. SJA is unfortunately not yet a standard procedure at all locations, however, the aquaculture industry is advancing and some of the companies in this study are about to implement SJA for certain safety challenging operations. Some operation managers have their own version of SJA, which we have named "a cup of coffee talk". All personnel involved in, e.g., a delousing operation, which involves 3-4 service vessels and sometimes a well boat, are invited for a cup of coffee on the feeding barge before the work starts. During the coffee chat the known hazards and safe work procedures are discussed, experiences are shared, and agreements are made on responsibilities and communication lines during the operation. Some jobs may last for several days, and new crews can be updated in the same kind of informal meetings. All companies are encouraged to do SJA and to document it with a few text lines in the log book. The log can be digital or a physical book. Notes in a book can be transferred to a computer assisted management tool by taking a picture with a smart phone and storing it together with other required documentation about the operation.

3.3 An improved approach to risk assessments

An improved approach to the current practice for risk analyses in the aquaculture industry was evaluated during four workshops. The approach is based on the preliminary hazard analysis (Rausand & Utne 2009). Operators, operational and shift managers, safety representatives and managers participated. Technology manufacturers were in addition invited to workshop 3 and 4.

Overall, the risk assessment steps in NS5814 were followed (Section 2.1). The following changes in the work process were made compared to today's practice in the Norwegian aquaculture industry: First, stakeholders were involved in the planning process. The workshop participants selected the operations for risk assessment based on their own experience and perception of hazards. The work operations were then described in detail by the participants, and a thorough description of the work tasks and involved objects/tools was established. The operators were fully involved throughout the process of developing risk-reducing measures associated with the identified hazards. The evaluation against risk acceptance criteria were not a central task during the process, but left to the HSEQ personnel (risk experts) to finish.

In the next paragraphs, the organisation of the workshops is explained in detail.

The room was organised with three or four large tables with markers and flip-over sheets. The participants were divided into groups, mixing professions and locations/vessels when applicable. The number of groups was adjusted according to the number of workshop participants, limited to five persons per group. Each group got markers of one specific colour: green, red, blue and black, respectively.

First, it was decided which operations to include in the workshop. Three or four operations of anticipated high risk were selected, equal to the number of groups. Each group was assigned with the task to describe one of the operations in detail, including use of gear and equipment. After a while, the groups rotated to the next table to fill in what they considered missing or erroneous in the description made by the previous group, bringing their markers. This continued until all groups had discussed all operations. This initiated a fruitful discussion on differences in work practices and exchange of practical experiences. Figure 2 illustrates the workflow of the groups.

The next task was to identify the hazards and possible incidents associated with the operations, also this time circulating the groups. This resulted in more comprehensive recordings of hazards than any groups produced on their own. Existing safety barriers were also identified, and causes and consequences were discussed. The groups worked until they felt that they had no more relevant input.

The risks were described and evaluated against risk acceptance criteria set up by the organisers beforehand, if it was within the timeframe of the workshop. The participants were instructed not to spend too much time on disagreements in assessing the severity of consequences or probabilities. They were encouraged to rather identify additional risk-reducing measures and discuss their potential effects.

The organising team documented the process continuously during the workshop and prepared the next sessions during breaks and other activities. The risk assessments were typed out and summarised in a worksheet table afterwards for all participants to share the results. The workshop should ideally last from lunch to lunch to allow time for discussions and reflections, and to include the risk evaluation step (Section 2.1).

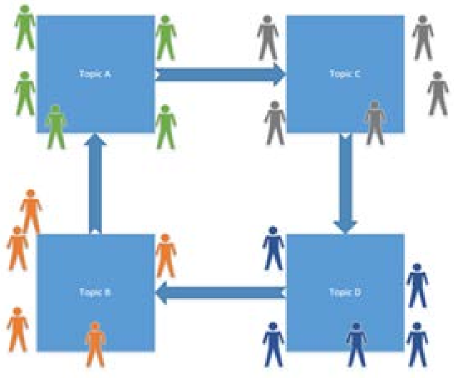

Figure 2. Groups and work flow in the risk assessment workshops (illustration by SINTEF Ocean).

The workshops resulted in detailed descriptions and risk assessments of work operations and equipment, as well as a list of preventive and risk–reducing measures. These can be integrated in the risk assessments of the participating companies. A common platform of understanding the work environments and operations were established between the operators and managers. Furthermore, the participants appreciated the possibility to exchange experiences across regions and companies.

4 DISCUSSION

The interviews in this study show that the motivation for performing risk assessments is relatively low in parts of the aquaculture industry, and that risk assessments often are performed with the primary objective to comply with regulatory requirements, rather than to improve safety levels. It is, nevertheless, evident that this situation seems to be improving (Holen et al. 2016). One explanation is that the authorities now have a stronger focus due to a high accident rate compared to land-based industries. Another is that the industry, which is rapidly growing, need to improve its reputation to recruit qualified workers.

Compared to, e.g., the oil and gas industry, the requirements and practices for safety work is at a considerably lower level (Holmen & Thorvaldsen 2015). The majority of the employees avoid "paper work". Hence, a more practical approach for improving risk management and risk assessments is needed for the fish farming industry.

The risk assessments are successful if the participants – the operators and their managers – gain a greater understanding of the risk picture in their working environment. The operators possess the practical experience and they daily face the dangers and make decisions to prevent accidents to evolve. The work should start by mapping the stages in the operations, which they know well, and identify the associated hazards. Causes and consequences should also be discussed in groups of operators, managers and HSEQ staff. Furthermore, if the managers follow up by documenting the process and establishing a shared action plan for risk-reducing measures, a major part of the regulatory internal control is implemented (Figure 1). Hence, it is a potential for merging requirements in different regulations into one management system.

The process of describing risks, and evaluate against acceptance criteria, can be finalised by the management supported by HSEQ personnel if they have participated in the earlier steps of the risk assessments. Decisions on which preventive measures to prioritise is closely connected to budget discussions at the management level, and the suggested approach will ensure that the management are familiar with the risk levels at the workplaces. In audits or accidents 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 possibly implemented. Thus, it is essential that the companies can document that they have performed thorough risk assessments as the basis for mitigating risks inherent in the work environment on vessels and fish farms.

The largest improvement of 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 documenting input on flip-over sheets lowers the threshold for contributions from everyone. Furthermore, the focus is shifted from lowering the risk numbers to acceptable levels, towards a shared understanding of the need for measures that can eliminate hazards or reduce the consequence of possible incidents. This approach thus supports the overall goal of the required risk assessments, namely to implement systematic preventive measures to maintain fish welfare, food safety, technical and personnel safety at aquaculture workplaces.

5 CONCLUSIONS

Previous studies indicate that the safety limits in aquaculture operations at today's sites already are reached due to harsher working environments and complex operations handling large energies in semi-manual operations. Risk assessment is a mandatory part of the internal control regulations and is a core activity in risk management systems. The practices for risk management varies considerably between companies in the Norwegian aquaculture industry. Hence, there is a potential for improving the situation considerably by implementing a systematic and standardised approach to risk management and risk assessments in particular.

To improve the safety level at workplaces, the operators need to be aware of the safety challenges in their working environment. An improved approach for risk assessments based on preliminary hazard analysis has been evaluated in cooperation with the aquaculture industry. The largest difference compared to the present practice is to describe the operation in detail and assess the hazards associated with each task, instead of merely listing general hazards and assigning risk levels. The method has been evaluated in a series of workshop and showed good involvement of the operators. When risk awareness and control is achieved in daily work, the next step should be to identify indicators for assessing risk levels during operation and maintenance of aquaculture farms.

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7 REFERENCES

Aasjord, H. & Holmen, I.M. 2009. Accidents in the Norwegian fisheries and some other comparable Norwegian industries. *4th International Fishing Industry Safety and Health Conference*, Reykjavik, Iceland, 2009.

AIBN (Accident Investigation Board Norway). 2014. Report on marine accident, capsising and loss of vessel – Maria – July 3rd 2012. (In Norwegian). AIBN Marine Report 2014/03.

AIBN (Accident Investigation Board Norway). 2015. Report on marine accident – Stålbjørn – July 31st 2013. (In Norwegian). AIBN Marine Report 2015/01.

Aven, T. & Vinnem, J.E. 2007. Risk management: With applications from the offshore petroleum industry. Springer Science & Business Media.

Bernard, H.R. 2006. Research methods in anthropology: qualitative and quantitative approaches. AltaMira: Walnut Creek CA, USA.

Bjelland, H.V., Føre, M., Lader, P., Kristiansen, D., Holmen, I.M., Fredheim, A., Fathi, D., Grøtli, E.I., Oppedal, F., Utne, I.B. & Schjølberg, I. 2015. Exposed Aquaculture In Norway: Technologies for robust operations in rough conditions. *MTS/IEEE OCEANS15*, Washington DC.

Carvajal, A., Slizyte, R., Storrø, I. & Aursand, M. 2015. Production of High Quality Fish Oil by Thermal Treatment and Enzymatic Protein Hydrolysis from Fresh Norwegian Spring Spawning Herring By-Products. *Journal of Aquatic Food* 24: 807-823.

Directorate of Fisheries 2016. Escape statistics. http://www.fiskeridir.no/Akvakultur/Statistikk-akvakultur/Roemmingsstatistikk (Accessed: 2017-01-07).

Food Safety Authority Norway 2017a. Violations on the Animal Welfare Act. (In Norwegian). http://www.mattilsynet.no/fisk_og_akvakultur/fiskevelferd/matilsynet_har_anmeldt_to_oppdrettsselskap_for_brudd_paa_dyrevelferdsloven.24662 (Accessed 2017.01.10)

Food Safety Authority Norway 2017b. Regulatory requirements for delousing operations. (In Norwegian). http://www.mattilsynet.no/fisk_og_akvakultur/fiskehelse/legemidler_til_fisk/ansvar_ved_bruk_av_ikkemedikamentelle_avlusingsmetoder.24921 (Accessed 2017.01.10)

Holen, S.M., Utne, I.B. & Holmen, I.M. 2014. A preliminary accident investigation on a Norwegian fish farm applying two different accident models. *Probabilistic Safety Assessment & Management (PSAM) 12, June 22-27, 2014, Hawaii, USA.*

Holen, S., Utne, I.B., Holmen, I.M. & Aasjord, H. 2016 a. Occupational safety in aquaculture – Part 1: Injuries in Norway. Submitted.

Holen, S., Utne, I.B., Holmen, I.M. & Aasjord, H. 2016 b. Occupational safety in aquaculture – Part 2: Fatalities in Norway. Submitted.

Holmen, I.M. & Thorvaldsen, T. 2015. Good safety work – examples from different industries. (In Norwegian). SINTEF report A26675, Trondheim.

Holmen, I.M., Utne, I.B. & Haugen, S. 2017a. Organisational safety indicators in aquaculture – a preliminary study. *Risk, Reliability and Safety: Innovating Theory and Practice* - Walls, Revie & Bedford (eds). Taylor & Francis Group, London.

Holmen, I.M., Thorvaldsen, T. & Aarsæther, K.G. 2017b. Development of a simulator training platform for fish farm operations. *Proceedings of the ASME 36th International Conference on Ocean, Offshore and Arctic Engineering*. OMAE17 Trondheim, Norway. Submitted.

International Standardization Organization 2009. Risk management – Principles and guidelines. ISO31000:2009.

Jensen, Ø., Dempster, T., Thorstad, E.B., Uglem, I. & Fredheim, A. 2010. Escapes of fishes from Norwegian sea-cage aquaculture: causes, consequences and prevention. *Aquaculture Environmental Interaction*.1: 71-83.

Norwegian Labour Inspection Authority (NLIA) 2017a. About the Norwegian Labour and Inspection Authority. http://www.arbeidstilsynet.no/artikkel.html?tid=79289#3 (Accessed 2017-01-14)

Norwegian Labour Inspection Authority (NLIA) 2017b. Working environment guide. http://www.arbeidstilsynet.no/workingenvironmentguide/ (Accessed 2017-01-13)

Norwegian Ministry of Labour and Social Affairs 1996. Regulation on systematic health, safety and environment work in enterprises (Internal control regulation). (In Norwegian). FOR-1996-12-06-1127.

Norwegian Ministry of Labour and Social Affairs 2005. The Working Environment Act. (In Norwegian). LOV-2005-06-17-62.

Norwegian Ministry of Trade and Fisheries 2004. Regulation on internal control to comply with aquaculture legislation. (In Norwegian). FOR-2004-03-19-537.

Norwegian Ministry of Trade and Fisheries 2005. The Aquaculture Act. (In Norwegian). LOV-2005-06-17-79.

Norwegian Ministry of Trade and Fisheries 2008. Regulation on the operation of aquaculture production sites (In Norwegian). FOR-2008-06-17-822.

Norwegian Ministry of Trade and Fisheries 2011. Regulation on technical requirements to floating aquaculture installations. (In Norwegian). FOR-2011-08-16-849.

Norwegian Ministry of Trade, Industry and Fisheries 2012. Regulation on the prevention of salmon lice in aquaculture plants. (In Norwegian). FOR-2012-12-05-1140.

Norwegian Ministry of Trade, Industry and Fisheries. 2014. Regulation on construction and supervision of smaller cargo ships. (In Norwegian). FOR-2014-12-19-1853.

Olafsen, T., Winther, U., Olsen, Y. & Skjermo, J. 2012. Value created from productive oceans in 2050. SINTEF report A23299.

Olsen, M.S. & Osmundsen, T.C. 2017. Media framing of aquaculture. *Marine Policy*, 76, 19–27.

Rausand, M. 2011. Risk assessment: Theory, methods and applications. Wiley, Hobroken, New Jersey, USA.

Rausand, M. & Utne, I.B. 2009. Risk assessment - theory and methods. (In Norwegian). Tapir Akademisk Forlag, Trondheim.

SINTEF Ocean 2017. Internal database for fatal accidents in Norwegian fisheries and aquaculture. Updated Jan. 2017.

Standard Norway (2008). Requirements to risk assessments. (In Norwegian). NS5814:2008.

Standard Norway 2009. Marine fish farms - Requirements for site survey, risk analyses, design, dimensioning, production, installation and operation. NS9415:2009

Stien, L. H., Dempster, T., Bui, S., Glaropoulos, A., Fosseidengen, J. E., Wright, D. W. & Oppedal, F. 2016. 'Snorkel' sea lice barrier technology reduces sea lice loads on harvest-sized Atlantic salmon with minimal welfare impacts. *Aquaculture*, 458, 29-37.

Størkersen, K.V. 2012. Fish first: Sharp end decision-making at Norwegian fish farms. *Safety Science* 50: 2028-2034.

Thorvaldsen, T., Holmen, I.M. & Moe, H.K. 2015.The escape of fish from Norwegian fish farms: Causes, risks and the influence of organisational aspects. *Marine Policy* 55: 33–38.

Utne, I.B., Schjølberg, I. & Holmen, I.M. 2015. Reducing risk to aquaculture workers by autonomous systems and operations. In L. Podofillini, B. Sudret, B. Stojadinovic, E. Zio & W. Kröger (eds.), *Safety and Reliability of Complex Engineered Systems*. CRC Press, Switzerland.