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Prepared for the worst? Emergency preparedness in Norwegian fish farming – Status and further improvements

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ABSTRACT

Norwegian fish farming has traditionally taken place in open net pens at the coast and in the fjords. With the aim of utilising new areas, innovative farm designs for open ocean locations have emerged in recent years. The government is developing a regulatory framework for operating in these areas. Increased distance to shore will require a robust emergency preparedness for personnel, fish, environment, food safety and material assets.

This article provides new knowledge regarding the status of emergency preparedness in the Norwegian salmon fish farming industry, describes the risk picture for coastal versus offshore production sites and suggests improvements for establishing emergency preparedness.

Methods include document studies, interviews, workshops and dialogue meetings with fish farmers, suppliers and authorities.

Findings support that preventive work and learning from accidents are seen as important, but also that emergency response plans may become too extensive and that more can be done when it comes to cooperation across companies. Key improvements include performing systematic emergency preparedness analysis, standardizing emergency preparedness performance requirements, and working together across companies. For offshore fish farming, synergies with other industries are key for the quality of emergency preparedness in the future.

1. Introduction

In the spring of 2019, a harmful algae bloom caused the death of 8 million farmed salmon in the northern part of Norway. A total of 14 fish farming companies were directly affected, and the importance of emergency preparedness in the industry became evident. Due to the scale of the event, several fish farms required assistance from the same vessels. The consequence was a scarcity of available vessels with pumps needed to remove dead fish from the net pens. There was insufficient capacity for grinding dead fish and disposal of ensilage as well. Furthermore, the need for personnel led to some workers having to work long hours with very little rest for several days in a row, potentially compromising personnel safety.

Today, fish farms are often placed in coastal waters close to shore (McIntosh et al., 2022), and the most common production technology for salmon (*Salmo salar*) in Norway is open net pens, which are accessed by boats. Operations at sea-based fish farms involve several hazards for personnel, fish, equipment and structures. Structural damages such as holes in the net may potentially impact the environment through escape of fish (Yang et al., 2020b; 2020a). The severe consequences of the algae bloom in 2019 made the importance of emergency preparedness evident, not only for individual fish farms but also for the whole fish farming industry.

While open net pen technology is a cost-efficient method that utilizes the natural advantages of Norwegian waters, the industry has challenges related to environmental issues, such as salmon lice, escapes, diseases, and occupational health and safety (Thorvaldsen et al., 2020a; Føre and Thorvaldsen, 2021; Størkersen et al., 2021; Neis et al., 2023).

Keeping salmon lice levels low is essential for fish welfare but also key for the companies' possibilities of production growth. The Norwegian coast is divided into 13 production zones and regulated by the so-called "traffic light system," where growth is determined biannually

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based on sustainability indicators. Currently, the influence of salmon lice on wild salmon is the only indicator being used (Osmundsen et al., 2020). Due to limited access to production licenses in coastal areas, as well as a lack of suitable areas for open net pens, the industry is developing and exploring new production technologies suitable for open ocean areas. This development was boosted following a government-introduced policy ("development licenses") aimed at technological innovation, which led to several new farm concepts designed for open ocean or offshore locations (Føre et al., 2022). To enable salmon production offshore, the Norwegian government has allocated three areas located further from the shore that are not covered by the current traffic light system production zones. A regulatory framework for operating in these areas is expected to be finalized in 2023.

Improvements in emergency preparedness for sea-based aquaculture systems are becoming even more important due to changes in the risk picture (Slette et al., 2022). The push for salmon production at sites further from shore means more exposure to wind, waves, and currents (Bjelland et al., 2015). For future emergency preparedness, there is a need to understand the impact of climate change on aquaculture, such as rising temperatures, raise of sea level, storms, hypoxia and ocean acidification (Froehlich et al., 2022). More extreme weather and environmental conditions will influence operational limits, considerations, and decisions related to safety for both fish and personnel (Morro et al., 2022; Yang et al., 2020a, 2020b). The increased distance to shore, increased number of fish per farm, changes in staffing and organization of work, increase in remote operations, automatization, and more demanding logistics (e.g., delivery of feed, weather window, and helicopter transport) have been identified as important aspects to consider with respect to emergency response and require a more proactive approach to emergency preparedness (Ministry of Trade and Fisheries, 2018).

Although essential for reducing the consequences of hazardous events in Norwegian fish farming, few studies have explored emergency preparedness in the industry. This paper will contribute to the literature on risk and safety in fish farming through three objectives:

a) provide knowledge of the status of emergency preparedness in Norwegian salmon fish farming.

b) describe the risk picture for coastal versus offshore production sites.

c) suggest improvements for establishing emergency preparedness for fish farming sites.

Section 2 provides background information regarding safety and risk management in Norwegian salmon farming, a brief description of emergency preparedness, and an overview of key regulations. Section 3 describes the materials and methods, followed by the results in Section 4, with findings about the status of emergency preparedness as well as risks for coastal versus offshore production sites. Based on this, the suggested improvements are presented and discussed. Section 5 concludes the paper.

2. Safety management and emergency preparedness in fish farming

2.1. Risk picture and safety management

Risks in fish farming can be described according to five dimensions: risks to material assets, personnel, fish welfare and health, environment, and food safety (Yang et al., 2020b). Fish farm workers must handle all these risks, which entails a lot of responsibility in their everyday work. The risks related to each of these five dimensions are described briefly below. See, for example, Holmen (2022), for a more thorough description of the risk picture in Norwegian fish farming.

Norwegian sea-based fish farms are in areas exposed to large forces from wind, waves, and currents. Fish farm technology is dominated by floating net pens, fastened together in a mooring frame, and operated from a feeding barge. Fish farm operations are assisted by work boats and service vessels, and well boats are hired for fish treatment and transport. Vessel maneuvering inside the fish farm is associated with a risk of damage to net cages, mooring ropes, or other components of the fish farm (Holmen et al., 2021). The constructions are flexible and dimensioned to withstand heavy forces; however, regular inspections and maintenance are needed to prevent damage to the net and fish escapes (Føre and Thorvaldsen, 2021).

Compared to other industries, the rate of occupational injuries and fatalities is high within the fish farming industry (Holen et al., 2018a, 2018b). The Norwegian Labour Inspection Agency (NLIA) registered 26–51 serious occupational injuries per year in the 2011–2021 period. During the same time period, employment in the Norwegian fish farm industry has nearly doubled from 7.4 to more than 14 million person hours. However, the injury rate per year has remained almost stable during these years. On average, there was one fatality per year in the period 2012–2022 (SINTEF Ocean, 2022). Falls, blows by objects, entanglement, and cuts are common injuries. Operations where cranes and capstans are used involve accident risk, and the main cause of fatal accidents after 2000 has been failures during lifting and maintenance operations.

Several hazards for fish welfare and health are found in salmon fish farming, including diseases such as pancreas disease and infectious salmon anemia. Harmful algae blooms (HAB), jellyfish, oil spills, oxygen or temperature deviations, storms, and winter ulcers on the fish may require slaughter or movement of the fish (Slette et al., 2022; Neis et al., 2023). Hypoxia due to low oxygen levels is a recurring issue in salmon fish farming that affects fish welfare negatively (Hvas and Oppedal, 2019). Delousing operations to remove salmon lice may lead to an increase in fish mortality due to handling and methods such as thermal and mechanical treatments (Overton et al., 2019). An increase in mortality or acute mortality triggered by HABs, handling, environmental conditions, or diseases might require emergency assistance from ensilage and service vessels to remove fish from farms (Neis et al., 2023).

The escape of farmed salmon is a hazard to both fish welfare and the environment. For companies, it is also an economic risk. A study applying 5-year average values to assess trends shows that the number of escaped fish has significantly reduced from 2006 to 2016. This is often linked to systematic preventive work, particularly stricter requirements for the technical conditions of fish farm structures (Føre and Thorvaldsen, 2021). While there are still variations between years, statistics find that the number of escaped fish has plateaued in recent years. Holes in the physical containment barrier—the net—are the most frequent cause of large escapes. Factors influencing the risk of holes in nets need to be monitored regularly to prevent fish escapes. National guidelines for emergency preparedness in the case of escape events exist and are a core part of each company's own contingency plans in the case of a fish escape event.

The fifth risk dimension, food safety, is paramount to manage according to strict regulations on allowed levels of chemical residues after disease of parasite treatment. Studies show that Norwegian fish farmers comply well with European Union levels (Hannisdal et al., 2020). Food safety is also closely connected to the reputation of the industry (Olsen and Osmundsen, 2017). Food safety is not within the scope of this paper; however, as food producers, fish farming companies must manage this risk dimension as well.

Fish farmers are required to have safety management systems that document compliance with a range of statutory regulations (Holmen, 2022). Systems include risk assessments, procedures, and nonconformity reports related to these risks. The authorities shall ensure that the systems are in place, while the companies implement and manage their own systems. While the purpose of procedures is to ensure safe work operations, some employees question the usefulness of procedures and find that there are too many of them (Thorvaldsen et al., 2020b). Furthermore, procedures are seen as documentation aimed to satisfy the inspectors if something goes wrong, rather than something that is actively used in everyday work (Størkersen et al., 2020). In addition,

personnel at the fish farms are not always adequately involved in conducting risk assessments and their implementation in the organization, thus affecting the ability to improve operational safety (Holmen, 2022).

Previous studies have underlined that operative personnel have competence that is valuable for assessing the hazards in operations (Thorvaldsen et al., 2020b; Føre and Thorvaldsen, 2021; Størkersen et al., 2021; Neis et al., 2023). Balancing production and protection is inherent in aquaculture operations, and conflicting objectives can be found (Størkersen et al., 2021). Since employees must ensure the welfare of the fish and prevent escapes, they may experience that production is prioritized at the expense of personnel safety (Thorvaldsen et al., 2020a; Thorvaldsen et al., 2015; Størkersen et al., 2021; Størkersen, 2012).

To ensure that safety work reduces the risk level in operations, it is important that risk assessments and safety procedures are developed together with employees who have detailed knowledge of the way the work is conducted. This is also a requirement in internal control regulations (Holen et al., 2018a, 2018b). Adequate training as a key to safe operations has also been highlighted in previous studies about risks in fish farming (Føre and Thorvaldsen, 2021; Thorvaldsen et al., 2020b). A study on occupational health and safety found that compliance with safety requirements was predicted by competence, underlining that training, including emergency exercises, is valuable for safety (Kongsvik et al., 2018a, 2018b).

2.2. What is emergency preparedness?

To identify which risks emergency preparedness should cover, risk assessments must be conducted. In this context, risk is defined as the combined answer to three questions (Kaplan and John Garrick, 1981): a) What can go wrong?, b) What is the likelihood of that happening?, and c) What are the consequences? Risk assessments provide an overview of identified hazards; why, when, and where this hazard may occur; the likelihood of the hazardous event causing harm; the possible consequences; and the need to introduce risk-reducing measures and barriers (Standard Norway, 2021). Even though one can identify the actions and barriers needed to reduce risk, it is not possible to reduce all the risks associated with running a business. It is the residual risk that emergency preparedness should handle. Emergency response plans enable businesses to handle any incidents that may occur due to residual risk.

Emergency planning (the establishment of emergency preparedness) generally consists of an emergency preparedness analysis and an emergency response plan, each with its own sub-activities. An emergency preparedness analysis describes several defined situations of hazard and accidents (DSHAs) that the emergency response plan must cover, and performance requirements that define how well the emergency response should function (Ranum et al., 2023). An example of a DSHA at a fish farm or vessel is "Man Overboard." An example of a performance requirement for this DSHA is "A person falling to sea during a work operation should be rescued from the sea within X minutes." In the Norwegian oil and gas industry, this performance requirement is set at eight minutes (Johansen et al., 2020).

2.3. Statutory regulations for emergency preparedness

Regulatory requirements for emergency preparedness in Norwegian fish farming relate to personnel (safety), fish welfare and health (infectious fish diseases and mass die-offs of fish and mortality due to harmful algae and jellyfish blooms), and environment (fish escape, harmful habitat conditions, and acute pollution). In the following sections, key regulations and actors for emergency preparedness are described. Table 1 gives an overview of the requirements, regulatory authorities, and associated risk dimensions.

The Aquaculture Operations Regulations (Ministry of Trade and Fisheries, 2023) specify requirements for an updated emergency response plan that describes planned actions to handle incidents such as infectious disease and mass death. The plans shall describe admission, treatment, transport, maximum length of stay for fish in the piping system, slaughter, and destruction. Furthermore, there are requirements for measures to prevent and manage mortality in the event of harmful algae and jellyfish, living environment conditions that are incompatible with the requirements of the species, and acute pollution. Finally, the emergency response plan should contain an overview of how escapes can be detected, restricted, and how escaped fish can be recaptured efficiently (including precautions when towing cages and handling fish and cages during loading and unloading). This makes restriction and recapturing part of emergency preparedness.

The act relating to protection against contaminants and waste (the Pollution Control Act) states that the person engaged in activities that may result in acute pollution shall ensure that the pollution is prevented, detected, stopped, and removed and that the impact of the pollution is limited.

The regulations concerning the performance of work, use of

Table 1
Overview of regulatory requirements and authorities relevant for emergency preparedness in the Norwegian fish farming industry. See Section 2.3 for a description of each legislation.

Topic	Regulation	Norwegian regulatory authority	Risk dimension	Purpose
Fish health and welfare	Regulations relating to the operation of aquaculture facilities (Aquaculture Operations Regulations) FOR-2008-06-17-822	Food Safety Authority	Fish welfare and health	Sets requirements for an updated emergency response plan for certain hazards.
Escapes		Directorate of Fisheries	Environment Fish escape	
Pollution	Act relating to protection against pollution and waste (Pollution Control Act) LOV-1981-03-13-6	Norwegian Environment Agency	Environment Food Safety	Ensure measures to prevent, detect, stop, remove and limit the effects of the pollution.
Occupational health and safety	Regulations concerning the performance of work, use of work equipment and related technical requirements (Regulations concerning the Performance of Work) FOR-2011-12-06-1357	NLIA	Environment Food safety	Requirements for a contingency response plan for emergencies when working with chemicals
Occupational health, safety, and work environment	Act relating to the working environment, working hours, employment protection, etc. (Working Environment Act) LOV-2005-06-17-62	NLIA	Personnel	Defines that the employer is decreed to notify the authorities in the event of work-related death, injury, or illness.
Fire prevention	Fire Prevention Regulations FOR-2015-12-17-1710		Material assets Personnel Environment	Set goals, plans, and measures to reduce the risk of fire in buildings and routines for evacuation and rescue and ensure that employees are trained in fire prevention and combat.

work equipment, and related technical requirements (Regulations concerning the performance of work) stipulate requirements for emergency response plans for emergencies when working with chemicals.

The Working Environment Act (Ministry of Labour and Social Affairs, 2005) requires a duty to notify in the event of work-related death, injury, or illness. The employer shall promptly and quickly notify the NLIA and the nearest police authority. Preparedness for this requirement is often described in the companies' emergency response plans.

The regulations relating to fire prevention specify requirements for established targets, plans, and measures to reduce the risk of fire in buildings, including routines for evacuation and rescue in the event of fires and routines that ensure that employees have sufficient knowledge and skills in preventing and combating fires.

Maritime safety and emergency preparedness require good interactions among public authorities, organizations, private enterprises, and individuals. The Ministry of Justice and Public Security (JBD), with the Directorate for Civil Protection and Emergency Planning, is the highest authority for emergency preparedness. The rescue service is coordinated administratively by JBD. Furthermore, the Ministry of Transport and Communications, the Ministry of Trade, Industry, and Fisheries, the Ministry of Defense, and the Ministry of Climate and Environment are also responsible for specified emergency preparedness functions in public society.

The Ministry of Trade, Industry, and Fisheries is responsible for facilitating safe marine operations, as well as climate and environmentally friendly activities, but does not have its own emergency preparedness resources for the fisheries and aquaculture industry. Fish farmers rely on both private and public resources to ensure their emergency response (see Table 2). For personnel safety, fish farmers rely on public resources, such as two Joint Rescue Coordination Centers (JRCCs), which have overall operational responsibility during search and rescue operations. For pollution, national resources such as the Coast Guard are in place, but these resources prioritize the environment, not farmed fish, in the case of, for example, an oil spill. For emergency preparedness related to events such as escape and fish mortality, fish farmers need different types of vessels that can help with recatching escaped fish or well boats that can transport the fish away from the fish farms.

3. Materials and methods

This paper is based on document studies, interviews, workshops with fish farmers and suppliers in the industry, and dialogue meetings with authorities. The combination of methods are well-proven in previous studies of safety in the seafood domain (Holmen, 2022). All activities were conducted during 2020–2022, and applied an approach that addressed risks for personnel (occupational health and safety), fish welfare and health, material assets and the environment.

Documents studied included mandatory regulations, company emergency response plans, and other literature that was relevant to understanding the requirements from authorities as well as internal requirements and plans in the companies.

Interviews with nine employees (operational managers and operative personnel) from two large fish farming companies were conducted based on an interview guide prepared by the research team. All interviews were conducted by telephone or in digital meetings. Topics for the interviews included emergency response plans, resources, drills, cooperation, and examples of unwanted events.

Three workshops and a webinar gathered employees from three major farming companies and representatives from the product and service sectors. These workshops provided knowledge about the status of emergency preparedness and potential new risks. As part of this work, emergency preparedness needs for coastal versus offshore fish farms were also addressed.

Dialogue meetings with representatives from two authorities (the Fisheries Directorate and the Norwegian Food Safety Authority) were held in 2021. These meetings focused on regulations and differences in the risk picture of coastal versus offshore fish farming and emergency preparedness from the regulators' point of view.

All participants in the interviews and workshops are anonymized in this paper. Quotes used in this article were translated from Norwegian to English by the authors.

The qualitative approach applied in this study is valuable for providing insight regarding the status and possible improvements for emergency preparedness in Norwegian fish farming. Still, it is important to note that a broader selection of participants for both interviews, workshops and dialogue meetings might provide additional insight. Furthermore, sources such as statistical data as well as investigation reports following unwanted events would be valuable input for future studies on emergency preparedness in fish farming.

Table 2
Key public actors for emergency preparedness relevant to Norwegian fish farming.

Actor	Description
The JRCC	Leads and coordinates rescue operations (on land and sea and in the air)
Coastal radio	Provides service and assistance to vessels in need (part of JRCC)
Rescue Helicopter Service	Part of the air force
Redningsselskapet ("Rescue vessel association")	A humanitarian organization for search and rescue; 26 manned rescue vessels
Norwegian Coastal Administration	National agency for coastal management, maritime safety, and emergency preparedness against acute pollution
Coast Guard	Part of the navy

4. Results

In section 4.1 the status of emergency preparedness is presented. This section is mainly based on interview data, and covers the topics preventive work, emergency response plans, cooperation, emergency preparedness drills and regulations. Section 4.2 presents the risk picture for coastal versus offshore sites, and is based on documents, interviews, workshops, webinar and dialogue meetings. Recommendations for improvements are presented in section 4.3.

4.1. Status of emergency preparedness

4.1.1. Preventive work

The interviews support that fish farmers consider their preventive work an important part of emergency preparedness. Examples of preventive work included procedures and risk assessments that formed the basis for the content of the procedures. One employee said, "Everyone takes part in the yearly risk assessments. We have a very extensive risk assessment that we go through every year; we go through all small differences between the fish farms." Furthermore, safety check rounds are done daily, weekly, monthly, and annually based on the risk assessments or the recommendations in the user handbook for equipment.

Maintenance of equipment was also considered important with respect to emergency preparedness, and employees explained that the companies used a nonconformity system preventively. To make reporting discrepancies easy, workshop participants said that some companies use nonconformity apps on their phones or tablets. Employees can take photos or make films and enter the deviation on site. It is easily accessible and therefore widely used. Deviations can also be found during safety check rounds.

Employees underlined the occupational safety risks during the interviews. Internal rules, such as not working alone, were mentioned as an important aspect with respect to emergency response. Additionally, falling into the sea was mentioned as a crucial event.

Prevention, through learning across fish farms, was also considered important. One of the staff employees said, "We are concerned with learning from serious incidents. We share follow-up reports where we have been able to shed light on an incident, with suggestions for improvement, and it is shared throughout the company." The sentiment was that if something happens at one farm, and they do not tell the other localities about this experience, chances are that it can also happen at other farms.

4.1.2. Emergency response plans

Emergency response plans describe companies' emergency preparedness for selected scenarios. One employee explained that their plans consisted of three parts: 1) an emergency response plan, 2) an "action plan" (what to do when the emergency has happened), and 3) a notification plan (who should be contacted when the emergency has happened). For instance, in the case of fish escape, it is a requirement that the Fisheries Directorate is informed as soon as possible.

The representatives from the companies that participated in interviews and workshops said that their plans were made by dedicated employees at the company's management. Local adaptations for each fish farm were subsequently made based on templates provided by the main office. Examples of local adaptations included location of equipment, such as recapture nets for escape incidents, meeting places, vessels with which one had contracts, and silage capacity.

Emergency response plans are updated regularly in meetings or safety check rounds. It is important that employees get to know the emergency response plans and suggest improvements. The interviews indicated that the emergency response plans were updated continuously, according to input from the employees after reports of nonconformities and after audits and input from various supervisory authorities. The changes were addressed at monthly meetings to ensure that all employees knew about the last updated version.

Overall, interviewees were satisfied with the emergency response plans. It was considered positive that they were developed by dedicated experts. The plans were standardized for all farms with the given local adaptations, and together with standardized equipment, this was considered to provide safe and predictable frameworks. However, one weakness was that emergency response plans were becoming increasingly extensive. During the updates, more points were added than removed. One employee said, "Emergency response plans are constantly changing. They have gotten bigger. Some points could be removed, but the plans usually get bigger."

4.1.3. Cooperation

Cooperation between fish farms within each company was seen as a positive aspect by participants in interviews and workshops. This relates to the 13 production zones and challenges, such as escape or mass mortality events.

Employees also valued standardized procedures and equipment so that they could easily work at different fish farms. An operations manager said, "We have four farms in the fjord here, and employees from other farms can come and help us." If something happens, there are additional crews nearby who can assist.

In relation to cooperation with other fish farming companies, the informants pointed out the advantage of common storage for recapture nets used in the case of fish escapes. If there were other companies nearby, they found that it would be good to cooperate and have nets and agreements with local fishermen who could help put the recapture nets out. In addition, companies had contracts with vessels in the case of mass mortality events. Some had agreements with external divers, while others had divers internally in the company.

Still, interviews indicate that not everyone agree that cooperation is optimal. One employee said, "The cooperation on emergency preparedness in the industry today is poor. This could be a key for the future. To cooperate and coordinate with neighboring fish farms and companies."

In a workshop, a company representative said:

"We learned a lot in our area considering the algae situation. Everyone contributed, fantastic! All neighbors and friends took part and helped, with well boats and ensilage vessels, fishers, it was handled well. But it is important to have a correctly dimensioned emergency preparedness if it happens again. The industry must talk together of a formalized cooperation that can coordinate resources when needed."

4.1.4. Emergency preparedness drills

In addition to general safety training, fire safety, heart starter training, and rescue drills are conducted. Separate emergency drills to handle the escape of fish are also carried out. All drills are documented, and management monitors that they are performed according to the plans.

One employee described their drills in the following way:

"Each location, each team, must have annual escape drills, annual escape course, annual man overboard drills, occupational health and safety events at the farms and fire drills. In addition, a larger drill is conducted yearly, based on emergency response plans. Last year, it was the processing plant that had a big drill. In 2018, we had a large drill in cooperation with the Directorate of Fisheries. It was planned well in advance but came as a surprise to the employees. It helped us update our preparedness for the better. I can recommend it."

All the informants talked about both large annual drills and smaller drills on the vessels according to the requirement from the Norwegian Maritime Authority that a drill should be performed at least twice a year. Some have monthly drills on each boat for each shift. There are different practices between farm sites. An operations manager said that each shift rehearses once a month, alternating between practical or tabletop drills. During practical drills, equipment on the boats is checked, survival suits are tested, and the crew practices how to rescue someone from the water. During the tabletop drills, employees take part in discussing the emergency response plans and help come up with scenarios and relevant measures.

Not all scenarios are suitable for drills. For instance, fire drills are performed as tabletop drills. One informant said that they practiced rescuing people out of the sea in good weather. Practicing in bad weather is considered too hazardous, even though such conditions are most demanding. Another said that he was unsure whether he would be able to pull an unconscious person out of the sea in bad weather. This challenge had been pointed out in a safety round, resulting in a fish farm company acquiring rescue equipment for all its boats.

4.1.5. Regulations

Even though the regulations require emergency response plans for different events, the industry has not established any performance requirements. Still, some companies said they had set certain response times. For instance, vessels that can remove dead fish from the net pens should be at the farm within 24 h of being altered. However, in the case of the algae bloom in 2019, the capacity to handle dead fish became a bottleneck because the capacity was not sufficient.

Several regulators perform audits at farms, as the requirements for emergency preparedness are defined in various regulations. Thus, fish farmers must handle different requirements separately. While discussing simplification of emergency response plans in a workshop, a fish farm employee stated, "It is not easy to simplify when so many authorities and certification companies have so much to say."

4.2. Coastal versus offshore – Hazardous events and accidents

To describe the risk picture for costal versus offshore fish farming sites, selected company emergency preparedness plans were studied.

Some examples of hazardous events defined in emergency response plans for coastal locations are as follows:

1. Serious personal injury

2. Workplace deaths
3. Missing person
4. Fire or explosion
5. Breakdown of facilities, fleets, boats, or equipment
6. Power outages and/or technical failures (onshore slaughterhouse)
7. Sea lice and resistance
8. Water oxygen level drop in the fish cage
9. Algae, jellyfish, and mass mortality of fish
10. Escape of fish
11. Fish diseases
12. Serious discharge or pollution
13. Crises related to food safety
14. Mass absence of employees
15. System failure

In the interviews, employees were asked to list three hazardous events perceived as critical for emergency preparedness without considering existing plans. Man overboard was mentioned by five out of nine informants, and three mentioned occupational accidents and fish escape events. Other events that were mentioned included heart failure and the mass mortality of fish. Entering the feeding barge from a vessel is also associated with occupational hazards.

While the same hazardous events will be relevant for open ocean fish farms, the technology or farm concepts, as well as the number of fish and distance to shore, may also introduce new risks. Several farm concepts are currently being developed for open ocean sites. One concept that has been applied to operate offshore is the Smart Fish Farm (SFF), owned by Salmar Aker Ocean. SFF was awarded development licenses through the development license policy. The application, publicly available through the Fisheries Directorate website in January 2021, serves as a relevant example when it comes to comparing emergency preparedness for coastal versus offshore locations. SFF will have a production capacity of up to 19,000 tons of biomass, which equals 24 commercial production licenses. The farm will have cabins for 28 people, a helicopter deck, rescue equipment, and a control room for operating the farm. The farm is set to operate 45 nautical miles outside the baseline.

The SFF application describes several risks, including vessel collisions, loss of stability, loss of position, helicopter accidents (use of helicopters will be the main transport method to and from land), and fire.

Under the heading "Emergency preparedness," the following hazard and accident events are listed:

1. Serious personal injury or acute illness
2. Fire on board
3. Structural damages
4. Collision
5. Loss of position
6. Fish escape
7. Loss of fish health
8. Extreme weather
9. Missing personnel
10. Uncontrollable discharge of possible environmentally harmful substances

The SFF application states that each of these events will be assessed with regard to scenarios, barriers, escalating factors, weakening of central safety functions, occupational risk, environment, material assets, and fish and implement an emergency preparedness strategy based on the risk assessments.

While the hazards listed in the SFF application overlap with the events listed in the emergency response plans for coastal locations, extreme weather is explicitly mentioned for the SFF. In combination with more extreme weather conditions, the participants in workshops also highlighted the increased distance from shore, making emergency preparedness more challenging than traditional coastal fish farming.

Thus, the scenarios for fish farming further from shore may differ from coastal locations. Establishing emergency preparedness for coastal versus open ocean fish farms is "two different worlds" according to one authority representative.

Discussions in workshops and dialogue meetings with representatives from the authorities identified some additional accident events for offshore fish farming: helicopter transport accidents, cyber security events, sabotage to the farm, and loss of power. The introduction of helicopter transport was highlighted as a change that would require more emergency preparedness compared to costal locations due to stricter regulations. This was also brought up in an interview:

"We need to distinguish between open ocean and conventional facilities near shore. Fish farms that are open ocean will be subject to a different regime, where one must base emergency preparedness on helicopters, for instance." (Fish farmer).

Cyber security was also thought to become more crucial, considering developments related to remote operations and automatization, which in turn may affect the welfare of the fish, as well as the safety of the personnel. Furthermore, scale was pointed out as an important difference—meaning the scale of consequences (e.g., escape of fish or fish mortality) but also the basic condition that there are live fish involved if an undesired event occurred.

"The consequences of stopping oil production are, very simplified, the oil can be pumped up later. The consequences of stopping when working with living animals can be terrible, considering fish health and welfare. (…) It is important to consider the fact that we are working with live animals. They have intrinsic value and deserve to be treated with respect." (Authority representative).

Authorities were also concerned with providing the correct support for the fish farm companies to help them identify their risk profile and the appropriate level of emergency preparedness for their operations.

4.3. Recommendations

This section presents recommendations for key improvements in emergency preparedness at fish farms. The findings presented in the previous sections indicate that fish farming companies are concerned with preventive work, the establishment of plans, training and drills, cooperation, and compliance with regulations. Establishing emergency preparedness for offshore sites requires a systematic approach that ensures the availability of key resources for different events. Furthermore, a systematic approach is important to address emerging risks not mentioned by the informants such as rising sea temperatures due to climate change, that may have severe consequences for fish welfare and mass mortality of farmed fish (Froehlich et al., 2022; Neis et al., 2023). Some of the suggestions described here, such as avoiding extensive and complicated written procedures and involving operational personnel to ensure well-functioning and suitable emergency response plans, are in line with previous research regarding safety management for personnel safety and the escape of fish (Thorvaldsen et al., 2020b; Føre and Thorvaldsen, 2021; Thorvaldsen et al., 2015; Størkersen et al., 2020; Holmen et al., 2018). In general, safety measures that fit well with the reality of workers, and align with the work practice, are considered to have higher practical relevance than other measures.

Emergency preparedness analysis: A company may reduce risks by, for example, implementing technical measures, such as safety nets or operational procedures to be followed by personnel. However, all risks cannot be removed. Due to residual risk, incidents may still occur. To ensure that incidents are handled in an efficient and planned way, an emergency response plan should be established.

The results indicate that it is not common practice within the fish farming industry to perform a systematic emergency preparedness analysis. The main purpose of an emergency preparedness analysis is to provide input into the emergency response plan. First, it is recommended that DSHAs are established based on risk assessments. For each DSHA, an assessment of how hazards should be handled must be

conducted to establish an emergency response strategy. Conflicting objectives related to different DSHAs should also be addressed in this analysis. By performing a thorough emergency preparedness analysis, fish farmers can build upon their risk assessments and ensure that the established emergency response reflects residual risk.

Standardized emergency preparedness performance requirements across companies: Performance requirements should be established to define the effectiveness of the emergency response. While cooperation across companies is found, this study indicates that there are no common requirements for the fish farming industry (e.g., response time in different emergency scenarios, such as man overboard or mass mortality of fish). In comparison, the oil and gas industry has established some emergency preparedness performance requirements across companies, which ensures the same level of emergency response across the industry. For instance, one requirement states how fast an ill or injured person shall be transported to an onshore hospital, and another states how fast a person shall be picked up from the sea in the case of a man-overboard situation. These are also relevant scenarios for the fish farming industry.

Emergency response plans: The emergency response plan shall be used by the emergency response organization when handling incidents. It is important that the emergency response plan is user friendly and that the content is relevant and up-to-date. A previous study argues that functional regulatory requirements may in fact increase the number of company- internal procedures as companies want to ensure proper documentation for regulators (Størkersen et al., 2020). Employees may question the number of procedures, as well as the usefulness of them (Thorvaldsen et al., 2020a). As discussed with the informants, it is important that the content in the emergency response plan does not continue to grow so that it is not perceived as too extensive, while maintaining a level of detail that is fit for the purpose and scope. The need to update the content should be continuously evaluated to ensure that learning points are reflected. As with risk assessments, it is valuable that operational personnel are involved in this process to ensure ownership of the plan (Holmen et al., 2018).

Distinguish levels of management: An improvement that seems helpful for fish farming companies is to describe the different levels of the crisis management team in the emergency response plan. This will ensure ownership of the plans and strengthen emergency preparedness competence in the organization. The 1st line of emergency response organization focuses on the operational aspects while handling an incident. It often consists of personnel present at the fish farm. The 2nd line of emergency response organization has a tactical focus during an incident. It is mobilized if an incident occurs and typically musters to a defined location on the company's premises. The 3rd line of emergency response organization has a strategic focus during an incident. It is mobilized if an incident occurs and typically musters to a defined location on the company's premises.

Training and drills are essential measures to support well-functioning emergency preparedness. The employees interviewed for this study also highlighted the importance of training. Drills related to emergency response plans will ensure that competence throughout the organization is sufficient. This allows different lines of management to gain knowledge about each other's roles and tasks, which enables good interaction in the case of an unwanted event. As found in previous studies, work practice and procedures do not always align (Føre and Thorvaldsen 2020; Thorvaldsen et al., 2020b; Holmen et al., 2018). D Drills are therefore useful for identifying gaps between emergency plans and practice. Examples of this could be available equipment and personnel, interactions with external actors, or response times. This learning can, in turn, be used for improvement.

Cooperation: The fish farming industry can benefit from increased collaboration across companies as well as with the authorities (Thorvaldsen et al., 2020b). This can be based on the production zone cooperation that fish farmers have already established. As described in this article, the fish farmers themselves stated that they envision more cooperation between the companies in the future regarding cooperation on resources and sharing storage for different equipment. This can entail a joint system for emergency preparedness resources. There is a common resource register operated by a common rescue central (HRS) today, of which some fish farmers are a part. Cooperation between companies to create a plan for a larger area, including shared emergency preparedness resources with other industries, will be a needed strategy for open ocean aquaculture further from shore.

Learning from previous events: Cooperation is also key when it comes to learning. While fish farmers share knowledge about accidents across farms, there are no obligations for companies to investigate accidents that have happened, and there is no system that allows companies to share their knowledge with other companies. This need or measure has also been discussed in the context of personnel safety and the escape of fish (Okstad and Tinmannsvik, 2019).

5. Conclusion

Norwegian fish farmers are required by regulations to perform emergency preparedness assessments and establish adequate emergency preparedness to manage residual risk in their operations. The residual risk may be related to personnel, fish, environment, food safety, and material assets.

This study shows that preventive work and learning from accidents are regarded as important and that regular drills are performed to practice emergency preparedness. On the other hand, emergency plans may become too extensive in some cases, and there is a need to improve cooperation across the industry regarding emergency resources.

The risks for coastal and offshore sites have many similarities, but new hazards and risks related to the transportation of fish, an increased number of fish in each production unit, and the distance to shore emerge for offshore sites. Novel fish farm designs, especially open ocean fish farming further from the coast, will require specific plans and competence to establish the needed level of emergency preparedness.

Based on the status presented in this study, the recommended improvements are to perform a systematic emergency preparedness analysis, standardize emergency preparedness performance requirements across companies, and focus on user-friendly emergency response plans that distinguish the different levels of crisis management in the companies. Furthermore, increased cooperation on emergency resources, as well as learning from hazardous events, may improve fish farm emergency preparedness. For open ocean fish farming, rather than concentrating on individual fish farms, the industry should look at the totality of farms and establish emergency preparedness that will serve all companies. Strengthening offshore emergency preparedness systems will also be beneficial for coastal fish farms in terms of increased attention, competence, and available resources. Synergies with other ocean-based industries, both established and emerging, are also key to improving the quality of emergency preparedness in the fish farming industry in the future.

CRediT authorship contribution statement

Trine Thorvaldsen: Conceptualization, Methodology, Data curation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Project administration. **Cecilie Salomonsen:** Methodology, Data curation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Stine Albertsen Ranum:** Data curation, Investigation, Writing – original draft, Writing – review & editing. **Petter Trædal:** Data curation, Investigation, Writing – original draft, Writing – review & editing. **Andreas Misund:** Methodology, Investigation, Writing – original draft, Writing – review & editing. **Ingunn Marie Holmen:** Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

The data that has been used is confidential.

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