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Innovations for improved emergency preparedness in the Norwegian aquaculture industry

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Abstract
The Norwegian aquaculture industry is a leading producer and exporter of Atlantic salmon (*Salmo salar*). Open-net pens accessed by boats are the most common production technology. Even though emergency preparedness is important for the safety at these fish farms, few studies have addressed their status and potential for improvements. In case of an incident, public emergency preparedness resources are used according to the following order of prioritization: 1) life and health, 2) non-replaceable natural resources, 3) industry values. Industry values in this context entail the fish, their health and welfare, and preventing fish escapes. Regarding the status of emergency preparedness, interviews showed that fish farmers base their emergency preparedness plans on systematic risk mapping and governmental legislation as well as their own and others' experiences. Since industry values are not a priority for public resources, companies must rely on private resources to protect their biomass and material assets. This paper describes innovations that may increase the efficiency and quality of operative emergency preparedness within the fish farm industry. The "*operative emergency preparedness support team*" can support the fish farmers in case of an accident, while "*algae forecasting*" can provide the fish farmers with information about algae blooms that are harmful to the fish. Custom-designed "*emergency preparedness vessels*" may assist the fish farmers with trained personnel and emergency equipment for different scenarios. "*Training*" is improved training concepts for emergency drills, using simulator technology.

Keywords: Aquaculture, fish farming, emergency preparedness, innovations, training

1. Introduction

The Norwegian aquaculture industry contributes significantly to Norway's foreign trade (Statistics Norway 2022). Atlantic salmon amount to 93% of the farmed seafood production in Norway (Directorate of Fisheries 2020). The fish farming industry is characterized by multiple risk dimensions: risk to material assets, fish welfare and health, risk to the environment, food safety, and personnel safety (Yang et. al. 2020). The risk picture associated with fish farm operations is complex and hence adequate risk management and emergency preparedness are essential for the industry's sustainability as well as the safety of the workers (Holmen 2022; Thorvaldsen et al. 2020).

In October 2022, in the space of 24 hours, three incidents occurred in Norwegian coastal waters. First, a freight vessel had an engine breakdown in the second-largest aquaculture area of Norway. With a speed of 1.5 knots, it was drifting towards land. Luckily, when its

distance to land was only 0.3 nautical miles, the Norwegian Coastal Guard was nearby with a vessel equipped for towing and managed to fasten a towline and tow the freight vessel away from shore (www.brunsvika.no 2022). Secondly, later in the same area, a wellboat loaded with infected fish ran aground (Nordeide 2022). Just in time, a towboat and a boat from the Norwegian Society for Sea Rescue attached tow lines to the wellboat's stern and bow respectively. Thirdly, another incident occurred in the same waters when a fishing boat was in need at the same time as the local rescue vessel from the Norwegian Society for Sea Rescue was occupied with another rescue operation.

These incidents were all handled, but the potential loss each of these incidents could have caused was substantial. A drifting freight vessel could collide with the fish farm and cause the destruction of the structure as well as lead to fish escape. An oil spill from any vessel could cause mass mortality for the fish in the cages. If the wellboat had had to release water from the wells to free itself, further spreading of infectious agents from the sick fish on board could be a likely scenario. And if the boat from the Norwegian Society for Sea Rescue had left before the wellboat was free, they would not have had sufficient control over the wellboat because it needed two vessels to assist it afterward.

These incidents demonstrate that aquaculture companies must be prepared for a range of different emergency scenarios and may not always rely on public emergency preparedness. The complexity of operations, during which personnel, fish, and the environment must be protected requires specific emergency preparedness resources that are suited for this context. Therefore, innovations that fill emergency preparedness gaps in the fish farm industry may be valuable contributions going forward.

In this article, innovations are presented – based on knowledge about the status and uncovered needs for emergency functions and resources, as well as a description of key stakeholders. The following research questions are addressed:

- Who are the key stakeholders for emergency preparedness in the Norwegian aquaculture industry?
- What are the emergency preparedness status and needs of selected fish farming companies?
- How can innovations help to improve emergency preparedness in fish farming?

2. Background

2.1 *Norwegian fish farming*

Floating net pens are the dominant fish farm technology, accessed by workboats and dependent on manual labor. The boats have a variety of equipment, including large cranes, used on a daily basis for production. Specialized service vessels are used for heavy operations and maintenance of the fish farm components (Holmen et al. 2021). The fish farms are traditionally situated at sheltered locations inshore. Due to fewer available sites close to shore, more exposed locations with demanding weather and sea conditions have been taken into use for salmon farming (Bjelland et al. 2015). Technological innovations and new fish farm concepts enable the industry to expand to open-sea areas (Føre et al. 2022). The demanding work environment as well as the potentially serious consequences of hazardous events at the fish farms form the basis and requirements for the emergency preparedness they need.

Figure 1: An aquaculture site with open net pens, a feeding barge, and a work boat. Photo: Magnus Oshaug Pedersen, SINTEF Ocean AS.

2.2 *Regulatory requirements for emergency preparedness*

Mandatory regulations set requirements for emergency preparedness at Norwegian fish farms. **The Aquaculture Operations Regulations** (Ministry of Trade, Industry, and Fisheries 2008) require an emergency preparedness plan for a variety of defined hazards. Infection hygiene and fish welfare have to be secured in emergency situations, by implementing appropriate measures to deal with acute outbreaks of infectious diseases and mass mortality. Furthermore, measures are required to prevent and manage mortality from harmful algae and jellyfish; ensure living environment conditions that suit the species' requirements; and manage acute pollution events. Finally, the Aquaculture Operations Regulations require that the emergency preparedness plan contains an overview of how fish escapes can be detected, restricted, and the fish recaptured. This includes precautions when towing cages and handling fish and net cages during fish deliveries.

The Pollution Control Act (Ministry of Climate and Environment 2023) states that anyone who carries out activities that may cause acute pollution must ensure that they prevent, detect, stop, remove, and limit the effects in the case of pollution.

The regulations concerning the performance of work, use of work equipment, and related technical requirements (Ministry of Labour and Social Inclusion 2011) set requirements for an emergency preparedness plan regarding work with chemicals.

The **Working Environment Act** (Ministry of Labour and Social Inclusion 2022) sets requirements for the duty to notify in the event of work-related death, injury, or illness. The employer must immediately and in the quickest way notify the Labour Inspection Authority and

the nearest police authority. Routines for occupational accident reporting are often described in the companies' emergency preparedness plans.

The regulations relating to fire prevention (Ministry of Justice and Public Security 2015) set requirements to reduce the risk of fire in buildings, e.g., routines for evacuation and rescue in the event of fire and routines that ensure that employees have sufficient knowledge and skills in preventing and combating fire.

The Ship Safety Act (Ministry of Trade, Industry, and Fisheries 2021) and the **regulations on safety management for small cargo ships, passenger ships and fishing vessels, etc.** (Ministry of Trade, Industry, and Fisheries 2017) set requirements for emergency preparedness on board vessels.

3. Methods and materials

The methods used in this study were document studies, interviews, and workshops with key stakeholders within the aquaculture industry. The information gained from the informants has been treated anonymously and has been handled according to the principles of the Norwegian Data Protection Official for research ("Sikt" 2022).

This study is part of a larger project aiming to improve coastal emergency preparedness through innovations. The project was conducted in close cooperation between industry actors and researchers. Several workshops have been conducted during the period 2020-2022, involving various stakeholders such as the Norwegian Society for Sea Rescue, the local municipality, and county administration. Separate workshops were conducted to discuss and iterate on the design of potential innovations presented in this article.

To recruit informants for the interviews, seven companies of different sizes and from different regions of Norway were selected and approached through e-mail and telephone. Informants from the fish farms represent both small and large companies, situated along the Norwegian coast from the western to the northern parts. In addition, interviews have been made with local government, the county administration, insurance companies, and the Norwegian Coastal Guard.

An analysis of the existing emergency preparedness and the identification of gaps was conducted before the interview study. Examples of gaps were: towing capacity, oil spill equipment and competence, pumping capacity, firefighting competence, recapturing escaped fish, coordination of resources, and warning in acute incidents.

These gaps were the foundation for the interviews. An interview guide was developed and divided into two main sections. First was a section with open-ended questions, allowing the participants to talk freely about the topics at hand, such as the status of today's emergency preparedness, which services they have in-house and which they hire, and cooperation with other fish farm companies. The questions asked were, e.g., "How do you work with emergency preparedness today?" and "How do you coordinate emergency preparedness between different aquaculture companies?" The second part of the interview guide was a structured section that listed gaps and had the same questions for each gap, namely whether the participants agreed that it was a gap in the fish farming industry. They were asked to rate the importance of measures to reduce the gap, from low importance (1) to high importance (5).

All interviews were conducted in person by two researchers, one taking detailed notes and the other researcher asking and following up on the questions. The interview data were thereafter analyzed, and quotes used in the article were translated from Norwegian to English by the authors.

A mapping based on documents, interviews, and workshops identified a variety of stakeholders related to emergency preparedness in the aquaculture industry.

4. Results

This section presents key stakeholders, status, and needs for emergency preparedness in the Norwegian fish farming industry, and innovations for improved emergency preparedness for sea-based aquaculture.

4.1. *Stakeholders*

Key stakeholders are presented in Figure 2. Within each stakeholder category, the employees interact with one another at different levels within each organization.

One important category of stakeholders is the **service providers** to the aquaculture industry (shown in light blue in Figure 2). They are hired on demand by the fish farming companies and include service vessels, diving services, wellboats, towboats, silage boats, feed boats, veterinarians, and fishermen on contract to assist in case of a fish escape. All these stakeholders can contribute if an incident occurs and are all a part of the emergency preparedness plans that each fish farming company has.

Governmental stakeholders are another important category when considering emergency preparedness. This stakeholder category can be divided into three subgroups. The first group (shown in light green in Figure 2) is stakeholders that respond immediately to an incident (public emergency preparedness resources). These are the Joint Rescue Coordination Centers, Telenor Coastal Radio, the Norwegian Society for Sea Rescue, Norwegian Coastal Administration, Norwegian Coastal Guard, the police, Emergency Medical Communication Centre (EMCC), and the local fire brigade.

The second group (shown in dark green in Figure 2) is the Ministries (Justice and Public security, Defense, Transport, Trade, Industry and Fisheries) and the Norwegian Directorate for Civil Protection, Directorate of Fisheries, Norwegian Maritime Directorate, Norwegian Labour Inspection Authority, and Norwegian Food Safety Authority. These stakeholders are responsible for the regulatory framework of the industry, as well as inspections. The third group of authority stakeholders (shown in medium green in Figure 2) is the

Figure 2: Stakeholders with regard to emergency preparedness in the aquaculture industry

local municipality and county. Their interest in emergency preparedness for the aquaculture industry is to ensure that an incident can be dealt with in a safe manner.

The aquaculture industry sometimes assists governmental stakeholders. Aquaculture workers and vessels are often nearby sea-based incidents and assist Joint Rescue Coordination Centers in rescue operations. Furthermore, aquaculture vessels may be used as a resource for oil spill preparedness: conducting drills, deploying oil spill equipment, collecting oil spills, and carrying out temporary oil storage. Some aquaculture companies practice together with the local fire brigade. When a public body such as the fire brigade works closely with a fish farming company, this is considered to have mutual value for both parties. The aquaculture industry has boats with water cannons, and they can be better suited for firefighting in areas that may be difficult to access for larger boats.

Insurance companies (shown in yellow in Figure 2) are stakeholders with an economic interest in the aquaculture industry and its service providers and want their customers to have as good a emergency preparedness as possible.

The final group (shown in grey boxes in Figure 2) consists of **companies that offer various emergency preparedness services** to fish farming companies and other industries. NOFO (Norwegian Oil Protection Association for Operators' Companies) is a private company securing area emergency preparedness on the Norwegian Continental Shelf that is shared between several oil companies. Vessels from the aquaculture industry may be under contract with NOFO. Another stakeholder is BarentsWatch, which is part of Norwegian Coastal Administration and is a web application that provides information that the aquaculture industry uses in a normal day's work, but which also is important when an incident occurs. It shows the spreading of fish diseases and other key information valuable to the fish farmers.

4.2. *Stakeholders' involvement in emergency preparedness*

In case of an incident, the public emergency resources described in the previous section respond to protect the values at risk. One accident may result in threats to either people, nature, private material assets, or all of these. If more than one is threatened, the response will be targeted according to the following order of prioritization:

(i) Life and health
(ii) Non-replaceable natural resources
(iii) Industry values

Based on the stakeholder mapping, the involvement of different stakeholders was sorted on a timeline that reflects the prioritized value protection listed above. This shows that some stakeholders play a key role at just one stage, and others at two or all three stages. *Before* an incident, government stakeholders, insurance companies, and providers of different types of training and courses on risk management service are prominent stakeholders for emergency preparedness in the aquaculture industry. Figure 3 shows which stakeholders are prominent *during and after* an incident.

The police and fire brigades' main task is to protect "life and health", and if there is time and available resources, they will contribute to saving "non-replaceable natural resources". Third in line comes industry values.

Norwegian Coastal Administration is responsible for cleaning up after oil spills, but interviews with the county government show that farmed fish are not a priority to them. Norwegian Coastal Administration will prioritize "non-replaceable natural resources", e.g., wildlife, nature, bird cliffs, and beaches.

Industry values in this context entail the fish, fish health and welfare as well as preventing escapes into the environment. This is the fish farmers' responsibility and should take into account events where several farms are affected, e.g., oil spills or harmful algae blooms. Governmental stakeholders are important in an emergency preparedness situation because they require

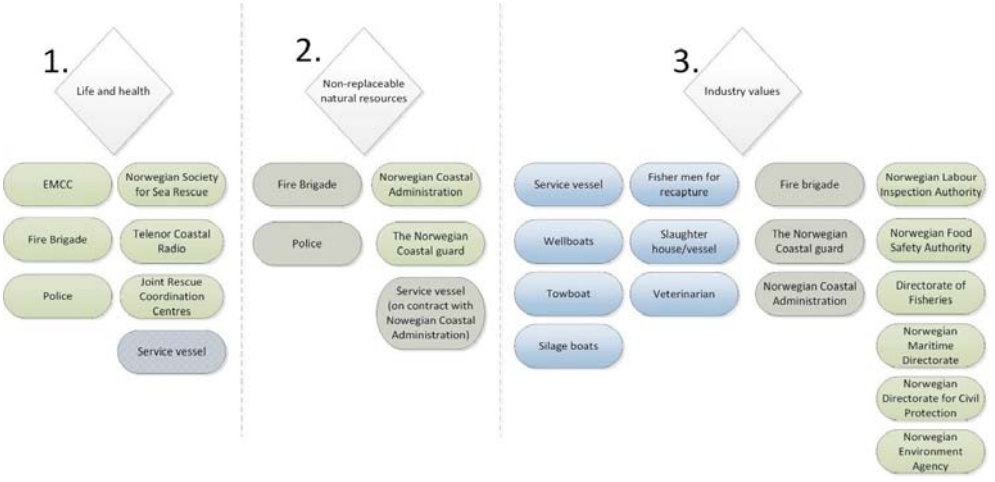

Figure 3: The figure shows which stakeholders respond to an incident, according to the public emergency resources' prioritization of which values to protect first. Public stakeholders that can contribute at multiple levels are shown shaded in other prioritized value categories. Green color indicates governmental stakeholders, blue colors are actors within the fish farming industry.

immediate reporting of incidents:

- Fish escapes must be reported to the Norwegian Directorate of Fisheries.
- Personal accidents must be reported to the Norwegian Maritime Directory (maritime personnel) or the Norwegian Labour and Welfare Authority (employees of the aquaculture industry).
- Oil spills must be reported to the Norwegian Environment Agency
- Fish mortality must be reported to the Norwegian Food Safety Authority.

- **4.3.** ***Emergency preparedness status and needs within the aquaculture industry***

Regarding **the status** of emergency preparedness, interviews showed that there were several gaps in emergency preparedness and the needs to fill the gaps were qualitatively rated by the informants (see Table 1). Interviews also show that fish farmers base their emergency preparedness plans on regulatory requirements, systematic risk mapping, as well as their own and others' experiences. This may explain why some incidents, such as e.g., oil spills, are not prominent in the fish farmers' emergency plans. When risk

Table 1: Emergency preparedness needs, identified gaps and importance rating (low= nice to have, medium=should have, high=must have).

Emergency preparedness needs	**Is this a gap in the fish farming industry?**	**Importance rating**
Equipment for recapturing escaped fish	It is a need for external assistance, but this is covered with today's arrangements.	High
Oil spill response equipment	There is a gap because they lack their own equipment ready to use.	Low
Towing capacity	There is a need for external assistance, but this is covered with today's arrangements for small-scale incidents.	High
Manpower resources to handle e.g. acute pollution/algae blooms/escapes	80% say no, they rely on each other.	High
On-scene Commander	75% claim this is covered within the organization.	Medium
Alerting ships on a collision course with regard to preventing escapes	It is considered "nice to have".	Low
Coordination of equipment/crew/boats, e.g., in the case of escapes/oil pollution/algae attacks	75% say no because a "crisis team" is set up across companies when needed to coordinate if there is a major accident.	High
Early warning and analysis to prevent algae attacks	Yes, this is a gap.	Medium
Resource register of emergency preparedness resources (boats, personnel, and equipment)	Yes, this is a gap.	Medium
Exercises with emphasis on coordination of personnel/actors during an emergency event	There is a variety of training, drills, and courses today, but there are still needs not covered.	High
Training of personnel for emergency management	There is a variety of training, drills and courses today, but there are still needs not covered.	High
Emergency management	50% see this as a gap.	Medium

assessments are carried out, employees at different company levels as well as external actors, such as suppliers, should be involved (Holmen, Utne, and Haugen 2018). The company emergency preparedness plans are adapted locally, to be suitable for the specific location of each fish farm

Needs for emergency preparedness resources are linked to potential hazards. As described in the stakeholder mapping, aquaculture companies hire external services to strengthen their emergency capacity. This is typically agreements with fishermen for the recapture of escaped fish, diving services, handling of silage, wellboats, towboats, slaughter vessels, and emergency drills.

A major accident in 2019 illustrates critical gaps in the fish farmers' emergency preparedness. In the spring of 2019, a toxic algae bloom affected many companies in the northern part of Norway and caused mass mortality of farmed fish across multiple farms. This incident showed that the first farms had little time to prepare, and fish farms further north were given a warning so that they could try to save their fish by moving them away from the algae. One informant explained:

> *"It was a major operation. Everyone was mustered and everyone contributed. Wellboats were released, purse seiners and other fishing boats helped out. We moved several million fish from north to south in our area. It happened in a fantastic way. Trawlers came and pumped dead fish out of the net cages, an incredible array of wellboats and service vessels, everyone jumped in and came and helped."*

This event also showed that most of the companies were dependent on the same emergency resources, although certain resources did not have the capacity to serve several fish farms at the same time. A lack of silage capacity became a bottleneck, and many cages risked collapsing due to the weight of the dead fish. One informant explained:

> *"We have emergency preparedness agreements with companies to handle incidents, but every fish farm had agreements with them. And the capacity was immediately consumed."*

The informants described that the towing capacity in one area was well covered, while for diving, wellboats, pumping, silage, and slaughtering the total capacity was too low. This illustrates the need for neighboring companies to cooperate in their emergency preparedness planning, to take such scenarios into account.

Informants from the insurance companies recommended that a formal emergency preparedness cooperation be established in the aquaculture industry, as has been done in other industries. Small companies can benefit from sharing resources with other companies in the same region.

During the 2019 algae bloom incident, several companies formed a joint "crisis team" to deal with the situation. One informant said that this was very valuable:

> *"Good relationships and networks were key explanations for why it went so well in 2019. Good networks both internally and externally. We know each other across companies at several levels, and everyone wants to contribute when such things happen".*

The "crisis team" performed tasks they had never practiced, and it took a few days to gain control over the situation. *"Everyone worked towards a common goal. Full mobilization and good cooperation,"* an informant said. When you sit together, you can prioritize which farm needs help first, and how emergency resource capacities should be distributed. *"It is coordinated at management level; it is not the operational manager who shouts the loudest who gets help first."*

The experiences from the toxic algae bloom event revealed several gaps and needs. The informants said that it could have been easier if they had a trained, professional emergency management team to lead and coordinate the emergency response, because of their lack of knowledge of available equipment, prioritization, and communication with the authorities as well as how to deal with media pressures. Resources such as a shared resource register were mentioned as valuable, and having a professional on-scene commander to take the lead.

Furthermore, emergency drills were highlighted by all informants as an important activity. Drills are often carried out several times a year, based on internal company decisions and regulatory requirements. The operational manager at each fish farm site is responsible for conducting drills and training with his/her staff. One informant pointed out that upgrading the operational manager's skills in how to conduct such drills and training has improved their quality. Another informant pointed out that one does not know what the next harmful incident may be, and therefore practicing general emergency management can be important. The need for external courses and expertise in how to conduct training and drills, and training for yet unknown incidents, was thus pointed out by our informants.

4.4 *Innovations*

The identified gaps and improvement needs formed the basis of novel concepts that may increase the efficiency of operative emergency preparedness in fish farming. These innovations were discussed and iterated in several workshops with representatives from the aquaculture industry.

The innovations are: operational emergency preparedness support, custom designed emergency preparedness vessel, training, and harmful algae forecasting (see Table 2), and they can be useful both before and after an accident. The concepts were

Table 2: Overview of innovations that will improve the emergency preparedness of the fish farm industry, which needs they relate to, and which stakeholders are regarded to be the most important for each innovation.

Innovations	Needs to be covered by this service	Key stakeholders	
Operative emergency preparedness support	Communication center and coordination of resources Facilitation of a "crisis management team" Resource register On-scene commander	Aquaculture companies Service vessels Wellboats Silage boats Towboats	Veterinarians Fish health personnel Joint Rescue Coordination Centers Telenor Coastal Radio Norwegian Coastal Administration Norwegian Coastal Guard Police
Emergency preparedness vessel	On-scene commander Crew (with proper training) Oil protection Towing capacity Silage capacity Fire fighting	Aquaculture companies Service vessels Wellboats Silage boats Insurance	Joint Rescue Coordination Centers Telenor Coastal Radio Norwegian Coastal Administration Norwegian Coastal Guard
Harmful algae forecasting	Environmental and algae monitoring during an algae bloom to detect if it will be a threat to the fish. Algae warning	Aquaculture companies Service vessels Wellboats Silage boats Fish health personnel	Veterinarian The Norwegian Seafood Federation Institute of Marine Research Directorate of Fisheries Norwegian Food Safety Authority
Training	Exercises with an emphasis on the coordination of personnel/actors in an emergency incident Training of personnel for emergency management Course in emergency management	Aquaculture companies Service vessels Wellboats Insurance	

co-created by the research team and key stakeholders that had particular ownership to the innovations.

The first innovation is **the operative emergency preparedness support team,** owned by a service- and wellboat company. The purpose of this service is to support fish farmers in the case of an emergency situation. Trained personnel can coordinate available resources in an area. This is of particular relevance in the case of major events that involve several aquaculture companies. This service could also contribute to establishing a crisis management team. Local knowledge and a register of available resources in the area can contribute to regional coordination. A part of the service can also include an "on-scene commander", who is physically present at the fish farm if needed.

The second innovation is a custom-designed **emergency preparedness vessel(s)**. The concept is owned by a ship design company. This is a well-equipped vessel with the possibility to assist fish farmers with trained personnel and emergency equipment on board. The crew on the vessel should be trained for emergency work, and might also include the on-scene commander described as a part of the "operative emergency preparedness support" team.

Emergency preparedness vessels may be designed in different sizes, with different types of equipment. A combination of small and large vessels can be useful, with different requirements for response time. Existing work boats and service vessels (15-26 meters) can, with small adaptions to the vessel and equipment, and a crew with special training and a short response time, provide added value for fish farmers. A larger vessel (40 meters) per production area could serve as a dedicated emergency preparedness vessel. A larger vessel can have more equipment on board, such as oil spill equipment, towing equipment, an infrared FLIR camera, light boat, firefighting equipment, fish-recapturing equipment, and a dedicated operation center.

The third innovation, **harmful algae forecasting,** is owned by a marine technology vendor.It can prevent the death of farmed fish. Algae blooms appear naturally along the coast. Historically, they have been more prominent in certain regions, but the number of blooms is expected to increase with a change in certain abiotic factors, like higher water temperatures. A forecast gives fish farmers time to act before it is too late. An important aspect of this innovation is to have the forecast as close to real time as possible, and algae forecasts must be accurate, to avoid false alerts for fish farmers. An important aspect is the timeframe of algae forecasting. A few hours' warning is not enough to act, as fish farmers ideally need days to conduct necessary measures such as moving the fish deeper into the net pens, canceling planned operations (such as delousing, net washing, or changing the net), or more drastic measures such as moving the fish in a wellboat or moving the cage itself to other/nearby locations with a license one is allowed to use. Slaughtering is the last option to mention. It requires a lot of resources to relocate the fish, and due to fish welfare, it should be avoided if possible. Therefore, the accuracy of the forecast is of high importance for it to be useful and trustworthy.

The fourth innovation is **emergency preparedness training** specially designed for the fish farming industry is owned by a safety training center. This will be an

addition to the training the companies already provide for their employees, with particular attention to emergency preparedness situations. This can be courses, tabletop drills, real-life drills, or a simulator-based emergency response exercise. The intention is to practice unexpected events in an environment that is as real as possible according to the participants' usual workplace (Kristensen et al., 2022). If good learning experiences can be achieved in a simulator, it will be possible to tailor the training itself so that it is as similar as possible to the real situations employees experience on board vessels or at the edge of a sea pen, so that the workers can practice and prepare for hazardous events in a harmless and realistic manner.

5. Conclusion

Emergency preparedness is an important part of maintaining safety in fish farming. Because the industry is changing, growing, and developing, emergency preparedness must be designed to handle risks for personnel, fish, the environment, and material assets.

This article has presented an overview of key stakeholders for emergency preparedness in Norwegian fish farming. Furthermore, the status of and some gaps/needs for a selection of fish farming companies has been described. New innovations that may be helpful to improve emergency preparedness within the aquaculture industry have been described. These innovations could help the aquaculture industry forward on the path to a prepared, skilled, and drilled future, ready to respond to incidents yet unknown.

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