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OCCUPATIONAL SAFETY AND HEALTH IN NEW SALMON FARMING CONCEPTS

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Employees in fish farming have exposed work environments, and salmon farming is one of the most accident-prone industries in Norway. Currently, new production concepts are being introduced. Concepts for the seawater phase are becoming more diverse, expanding from mostly open netpens along the coast, to include new designs such as semi-closed and submerged units for coastal and offshore sites as well as production on land. Along with new technologies, working conditions are transformed. The objective of this article is to study occupational safety and health (OSH) in new salmon farming concepts. The new concepts involve technologies that reduce manual labor, shield or remove humans from high energies or hazards. When routine operations become remotely controlled, personnel are removed from hazards, but other risks related to monitoring tasks may increase. Also, larger operations still require personnel and involve hazards and increase uncertainty. At the new salmon farming concepts in general, risks can potentially increase, despite improved safety management: This study shows how large investments and new technologies can reduce some hazards, but also lead to new organizing and deskilling, that may shift the entire foundation for decision making and safety management.

Keywords: Safety, OSH, OHS, salmon farming, aquaculture, workplaces, technology.

1. Introduction

In Norway, fish farmers have one of the most accident-prone occupations, and salmon farming is the main type of production (Holmen & Holen, 2023). Currently, the salmon farming industry is changing as new production concepts are introduced. Concepts for the seawater phase are becoming more diverse, moving on from mostly open net pens along the coast, to include new technologies such as semi-closed and submerged concepts for coastal and offshore sites as well as production on land (Afewerki et al., 2023; Misund et al., 2024; Oftebro et al., 2025).

Along with the new concepts, the working conditions are transformed. Technology that reduces manual operations at fish farms can reduce the risk of injuries and strain, but new concepts may also introduce new risks to the personnel (Thorvaldsen, Salomonsen, et al., 2023). No former studies have addressed OSH and conditions for working safely with these new salmon farming concepts.

The purpose of this study is to shed light on occupational safety and health in the current salmon farming concepts, including how safety science can inform and be informed by the safety management in the new salmon farming concepts.

2. About Norwegian fish farming

2.1 Risks and existing safety research

Official registries show that about 7200 people were employed at approximately 1000 fish farm sites along the Norwegian coast in 2023 (Directorate of Fisheries, 2025a). In addition, 2000 people work at hatcheries. Thousands of different vessels also operate in fish farming.

The Norwegian Labour Inspection Authority has registered 3-4 personal injuries per 1000 employees per year in aquaculture activities in the period 2015-2022, and there were 10 fatalities in total for the period from 2012 to 2022 (Holmen & Holen, 2023).

The most hazardous work operations in Norwegian salmon farming are crane operations, such as loading and lifting, and inspection of tanks (Holen & Holmen, 2025; Thorvaldsen, Kongsvik, et al., 2023). These operations often involve vessels and workers that do not have their main workplace at the fish farms, but who are contracted to perform or assist in specialized operations. Unwanted events such as mass mortality of fish must also be handled by the workers in the industry, regardless of the location of the farms, leading to high peaks in work pressure and possibly higher risk for the personnel (Neis et al., 2023; Thorvaldsen, Salomonsen, et al., 2023).

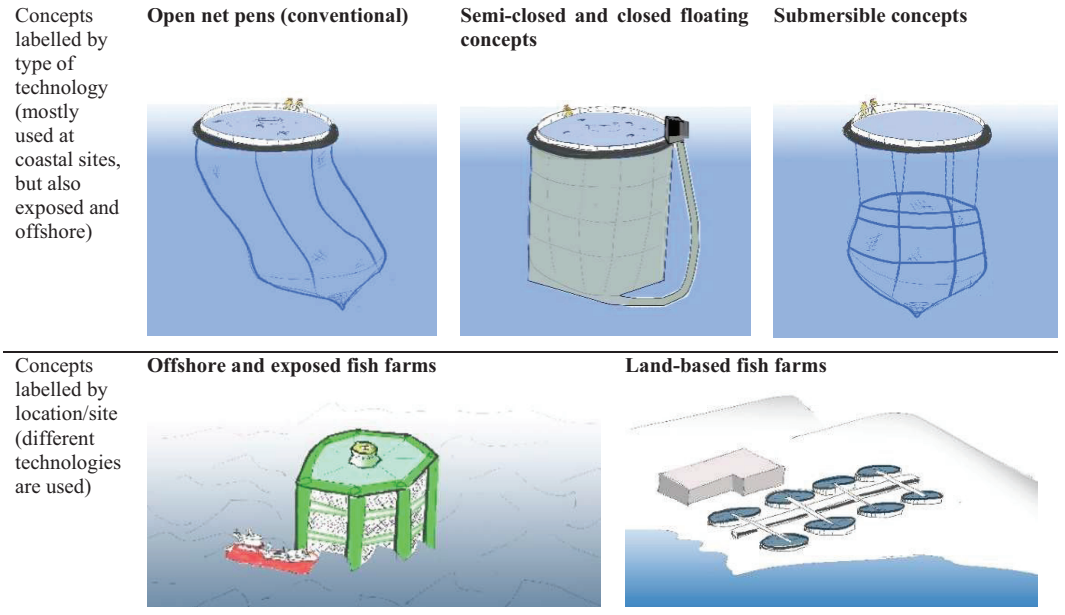

Figure 1: The main categories of salmon farming concepts. (Illustration: Cecilie Salomonsen/SINTEF Ocean AS)

Safety challenges in fish farming include poor planning, inadequate staffing, insufficient training and lack of time for maintenance (Gumdal, 2022; Kongsvik et al., 2018, 2019; Thorvaldsen et al., 2015). Fish farming employees report that production is sometimes prioritized at the expense of safety (Størkersen et al., 2021; Thorvaldsen et al., 2017, 2018). Goal conflicts have been widely described in organizational safety science by for example Reason (1997) and Hollnagel (2009). When the product is a live fish, the dilemma between protection and production becomes even more challenging (Størkersen, 2012).

In salmon farming, as in other industries, safety management has improved working conditions, but also shifted attention and resources from safe practices to formalities (Dekker, 2015; Størkersen et al., 2020; Thorvaldsen et al., 2021) introducing problems with formal safety management described by Provan et al (2019). In recent years, attention and professionalization of safety management in companies has increased, and this competence is crucial when introducing new technological concepts. Particularly at weather-exposed sites, the operational planning, maintenance and emergency preparedness is essential (Bjelland et al., 2025).

2.2 Current salmon farming concepts

Conventional open netpens is still the most common salmon farming concept in Norway, but many new concepts have appeared the last decade. Many of the new concepts were developed because of the "development permit policy" launched by the Norwegian Government in 2015. The aim of the policy was to spark technological innovation to solve challenges with fish escapes, lice and lack of area suited for salmon farming (Føre et al., 2022).

The new salmon farming concepts include *offshore and exposed*, *submersible*, *semi-closed and closed* concepts for sea farming, and *land-based* salmon farming (see Figure 1). Some of the labels indicate the areas in which production takes place (offshore, exposed and land-based). Others point to technologies (e.g. semi-closed, closed, submersible) that can be used at different locations. Each concept has certain characteristics, but there are also some overlaps. Land-based concepts use closed technology and are not exposed to the influence of the surrounding sea like sites using closed technology at sea.

The maturity of the concepts varies. Most of the concepts have been operating for a few years, while others are just beginning. Offshore farming is still in the planning phase, but some concepts designed for offshore locations are currently used at exposed sites.

3. Methods

The empirical data presented in this study is personnels' descriptions of working conditions and safety management in various salmon farming concepts. The data presented was collected in 2023 and 2024 using semi-structured research interviews. In total, 14 persons representing different concepts (Størkersen et al., 2024) were interviewed and four of the interviewees had mainly operational tasks, while 10 were managers within OSH or operations. Most had experience from several salmon farming concepts, while two informants (operating

personnel) only had experience from conventional concepts. Furthermore, four of the managers represented companies where the new concept was currently under design/construction, but they had previous experience from other fish farming companies.

Quotes used in the result section have been translated from Norwegian to English by the authors.

4. Results

The interviews show how occupational safety and health in the various salmon farming concepts are perceived. Most of the descriptions describe differences between conventional and new salmon farming concepts. See Table 1 for an overview of negative and positive implications for OSH in the new salmon farming concepts.

4.1 Common resource problems and new priorities

The interviewees emphasize that OSH in fish farming has improved over the years, although they still experience a scarcity of time, expertise, training, and other resources important for OSH. Particularly for conventional concepts, poor planning and lack of resources leads to conflicts between 'protection and production'. Here, many describe how not prioritizing safety is common, and that measures are implemented *after* an incident rather than before, i.e. a reactive approach to OSH. All informants in this study, regardless of concept, are concerned with and want more resources and a higher priority of OSH. The importance of top management's commitment is highlighted by the informants, as exemplified in this quote:

> *It comes down to priorities. Not everyone allocates resources internally, some give OSH responsibility to managers who are already busy with production setup, smolt and feeding. Then OSH becomes something you bring up only now and then.* (Management, several concepts)

Safety professionals working with the new concepts underline that more resources are put into safety management in their organizations. They describe new approaches to risk assessments and work procedures, including various forms of visualization with films or game aesthetics. They have introduced systems and solutions that make their work safer, such as peer involvement, training, resources and realistic safety management with procedures that fit the operations.

Several of the interviewees also request stricter safety regulations and more proactive authorities.

4.2 Larger structures and stronger forces

Most of the new concepts are large and designed to produce a much larger quantity of salmon compared to conventional concepts. The new designs could hold up to 1 million fish in one production unit. Potential positive outcomes of large dimensions and attention to OHS are stable working platforms, and thorough emergency preparedness plans. On the other hand, heavier equipment and bigger units of fish introduce new work operations, unfamiliar for the personnel. Some will operate in areas with harsher weather conditions than before, and many operations are more complex, with more equipment and involve personnel from several organizations.

> *The personnel think they know bad weather, but this [open offshore fish farming] will be different than what they know today.* (Management, new production concept)

4.3 Technology in operations

It is a goal for fish farmers to reduce operations involving the fish, to improve fish welfare. In the new salmon farming concepts, operations therefore include more technology and are more often remotely controlled.

> *If we're going to do something with the fish, we're pressing the keys. Nothing is manual labor. Most new concepts plan not to haul and lift the nets or lift the dead fish collector. No delousing.* (Management, new production concept)

The new technological solutions also have both positive and negative safety effects for the personnel involved. For the personnel, this means that daily operations are reduced to monitoring and maintenance.

Monitoring involves surveillance of the fish or operations through video or instrumentation shown on screens at remote control rooms on shore, at feed barges or vessels. Camera monitoring is a tool in remote feeding of the fish, autonomous checking and cleaning of farm equipment, or dispatching dead fish and waste. This is often combined with technology interpretating the fish' behavior, how much it eats, size and lice state, as well as biofouling and state of the net, moorings, etc.

Daily maintenance often involves operations with cranes, ROV's or heavy manual labor. The use of cameras, ROV and lifting equipment can reduce personnels' involvement in some of the hazardous operations traditionally performed. However, new equipment requires training, and there are risks related to installing, operating and maintaining equipment. For example, ROVs must be lifted into the sea or net pen, representing a substantial risk for personnel, especially in combination with wind and waves.

4.4 Less variation in everyday work

Technology and remote operations impact the work, as more people are moved to land-based control rooms. Personnel will perform mainly technical maintenance, instead of working close to the fish and the sea. In the interviews, some underlined how the psychosocial environment is important for good and attractive workplaces. Some expressed how they

strive to make the workplace and the job interesting as the work has become more standardized, and the working day is remote to the fish farm. While working in control rooms can have a positive influence on the predictability of the workday, it also has implications for the operators' understanding of the fish and the operations, not to mention their health. For instance, ergonomic issues with sedentary work must be handled. One of the informants points out that the work must be perceived as rewarding to ensure recruitment:

> *Another aspect that others don't talk about, but we do: How much fun will it be to work there?* (Management, new production concept)

Table 1: Challenges for OSH in new salmon farming concepts (construction, operations and organization).

Salmon farming concept	*Construction and equipment*		*Work operations*		*Organization*	
	Negative	Positive	Negative	Positive	Negative	Positive
Offshore and exposed fish farms *- Different technologies (including open and submersible technologies)* *- Weather-exposed offshore or coastal sites*	Much weather exposure, large dimensions, greater forces. Different concepts: Big heights or small spaces. Need of special vessels.	Larger concepts and equipment give stable working platforms. Powerful equipment, big cranes.	Advanced vessel operations and entering for personnel. Working in closed spaces and tanks.	Less manual work, less heavy work. Rarely or never delousing. Improved overview of fish and equipment due to more monitoring	Psychosocial working environment and workload.	Attention to emergency preparedness for people, fish and environment. Mostly predictable operations – avoiding periods of increased staffing and stress. Fewer tasks and lower staffing. Attention to collaboration between personnel from different disciplines.
Submersible fish farms *- Closed net pen, app. 30 m below surface* *- Coastal sites*	Large units and dimensions, heavy lifting with large cranes. High voltage. Closed space for divers.		Need for diving operations, and the operations become more complicated and hazardous. Much technical work.		Complex, complicated and advanced operations and maintenance.	
Semi closed and closed floating fish farms *- Different technologies* *- Coastal sites*	Large units and dimensions, requiring heavy lifting with large cranes.		Handling of specialized equipment. Diving in water currents.			
Land-based fish farms *- Closed technologies* *- Tanks on land, usually by the coast*	Chemicals, leaks. Large dimensions and heights. Hard floors. Exposure to aerosols.		More handling of chemicals. Cleaning fish tanks is heavy manual labor.	No work in bad weather at sea. Rarely or never delousing.	Interaction with different disciplines.	

4.5 Particularities for the new sea-based concepts

Despite more automation and remote operations in the daily production, the personnel at sea sites are still needed for less frequent larger operations. Common, but less frequent operations include transfer of fish from land to the farm, larger

maintenance, and transfer of fish from the farms to the slaughterhouses and production facilities. For sea-based systems, the risk may increase with harsh weather conditions and few weather windows to perform operations safely.

Planning operations was a topic in most interviews. Some expressed that planning, and coordination traditionally has been too lax in Norwegian fish farming, but this has changed with new concepts.

Traditionally, delousing operations involve risk for personnel as well as for escape and fish mortalities. A motivation for new concepts is to reduce the need for delousing operations, and fewer delousing operations are considered positive for OSH. Less delousing also means a more predictable production and improved chances to make good plans for the remaining larger operations.

4.6 Particularities for the land-based concepts

The safety planning was also illustrated in the following quote from an informant who used to work at sea, but now was involved in land-based salmon farming:

> *The reason why land-based farming is different is that they get routines from other industries. In the construction industry, for example, OSH has a major role. There, you can't skip SJA [safe job analysis] and work meetings "to get this building up in a f* speed". You must stay on your toes and don't sit back. You have to be "on" all the time. If someone thinks you can avoid the OSH work, accidents will happen.* (Management, several concepts)

Land-based fish farming stands out from the other concepts and is comparable to other land-based industries. The attention to OHS seen in other industries is considered positive by the informant.

An OSH challenges that land-based fish farms face is handling of chemicals. Chemical leaks may cause long term exposure to workers. In addition, there is a challenge related to working in the height due to the large dimensions of the fish tanks. Personnel may fall into the tanks, with or without water. During cleaning, the tank surfaces become slippery, and this increases the risk of fall injuries. Cleaning and other maintenance tasks expose the workers to aerosols. Strain injuries, due to hard floors or repetitive cleaning with heavy equipment, are also frequent and important to prevent.

4.7 Increased complex cooperative operations

All new concepts require more extensive collaboration with others outside each salmon farm organizational unit. Operations are more complex and demand more specialized competence, and more and different types of suppliers are involved than previously. For example, new concepts have increased the need for diving services, scaffolding builders, naval navigators, electricians, and welders. All must collaborate to ensure safe operations.

> *Perhaps one of the greatest challenges is that they must cooperate.* (Management new production concept)

Submersible concepts require diving operations, potentially complicated and hazardous for workers. Regarding submersible farms, one informant explains that:

> *We have a new occupational group that's got a bigger role: divers. We often hire them, there's considerably higher diving activity, and there are more operations and incidents related to OSH.* (Management, several concepts)

The diving operations at the submersible concepts include diving at lower depths than in conventional concepts, requiring hyperbaric chambers to be available as part of the preparedness. Deep diving is described as more hazardous. Also, the diver can become entangled in the equipment inside the net pen. Some of the maintenance must be performed inside a closed off net, because an opening can lead to fish escape. The operations thus must be thoroughly planned to ensure OSH.

5. Discussion

The data presented here provides insight into health and safety opportunities and challenges in the new salmon farming concepts, enabling a discussion on how to mitigate negative and unintended consequences of the new concepts.

5.1 Safety by design?

Prioritizing OSH in design can separate personnel from hazards, increase predictability and planning (Reason, 1997). In Norway, national regulations call for safe and healthy work environments, and previous studies from salmon farming argue that consideration of OSH must be included from the beginning of the design processes to reduce risk (Salomonsen et al., 2019; Thorvaldsen et al., 2020). Despite accident statistics, OSH was not a criterion when public policies boosted the innovation rate in salmon farming (Afewerki et al., 2023).

In the new salmon farming concepts, there is still risk for strain and injuries described in conventional concepts (Holen & Holmen, 2025; Sandsund et al., 2021). The new concepts have also introduced new hazards to personnel. While automation removes personnel from some hazardous operations, new hazards related to installing, maintaining and operating this technology may be introduced. Removing personnel from operations in the sharp end, shielding them from manual work and reducing their time at sea may reduce risks for injuries and fatalities. Still, monitoring tasks also require suitable

OSH measures. Measures that ensures the safety and well-being of the employees are therefore important.

5.2 Learning from each other

To prevent accidents and strain for personnel in new concepts, utilizing knowledge from 60 years of salmon farming, as well as from other industries is useful.

Some hazards are known. Limited time and personnel allocation has been a recurring issue in salmon farming that may result in stress, long working hours and lack of rest (Thorvaldsen et al., 2020, 2021). Previous studies show that conflicting objectives may emerge, sometimes leading the personnel in the operations to prioritize production and fish welfare over their own protection (Størkersen, 2012; Størkersen et al., 2021; Thorvaldsen et al., 2015, 2020).

Still, not all hazards are known. Learning from each other, across companies is therefore valuable. Fish farmers can learn from others designing and operating similar concepts, and established farmers using conventional concepts may also learn from farmers introducing new concepts. Government has required learning reports about the new concepts (Directorate of Fisheries, 2025b). However, these reports do not include descriptions of working conditions or OSH, and are not helpful for operational learning or training purposes.

In addition, safety research from other industries (e.g petroleum industry) can be used to improve safety in the new salmon farming concepts. If the salmon industry spends resources to learning, train and avoid the traps that are known, it may improve OSH moving forward. To provide some examples of this, some insights from other industries are discussed in relation to salmon farming below.

5.3 Improved collaboration

Findings presented here show that new concepts require more interorganizational cooperation, and complex operations involving several actors. Cooperation and use of contractors is becoming increasingly common in the salmon farming industry (Holmen et al., 2021; Kongsvik et al., 2025). Previous studies have revealed that large operations are associated with many tasks in a short amount of time, characterized by long work sessions, little rest, and challenges with coordination when many companies are involved in the same operation (Størkersen et al., 2021; Thorvaldsen et al., 2015). Research from other industries suggest that many organizational interfaces make communication difficult and increase the likelihood of misunderstandings, disagreements and information not getting through, thereby increasing the risk of accidents (Milch & Laumann, 2016). The personnel in new salmon farming concepts thus need skills to handle these interorganizational operations.

Although these operations are less frequent, and daily operations mainly involve monitoring and maintenance, the personnel must be trained to maintain safety in complex and dangerous operations.

5.4 Varied and skilled work

Taking care of the fish and solving practical tasks have been highlighted as positive aspects of working in salmon farming. This has traditionally also given workers the skills needed to perform critical operations safely (Størkersen, 2012). Embodied knowledge, which is only acquired through physical experience, has been found important for work safety and competence in other industries too (Almklov & Hepsø, 2011; Midtlyng, 2024; Størkersen & Thorvaldsen, 2021). The *automation conundrum* should be kept in mind when introducing automated technology: This concept describes that when more automation is added to a system, it lowers the situation awareness of operators and it is less likely that operators will be able to take over manual control when needed (Endsley, 2017).

In contrast, many salmon farming concepts aim for more remote operations and monitoring, although critical operations still require practical skills. In fish farming, operational safety has traditionally relied on decisions in the sharp end (Bjelland et al., 2025; Størkersen, 2012).

Remote operations and not being 'hands-on' to the production removes some of the opportunity for 'embodied knowledge' that supplements conceptual thought and theoretical insights (Almklov & Hepsø, 2011; Maslen & Hayes, 2022). Studies have discussed how direct field experience might influence decision making and risk acceptability (ibid). Thus, more autonomy could potentially involve the diminishing of important competence, and in turn influence risk understanding, decision-making and risk-taking behavior. For fish farming, it is therefore important to find ways to preserve important skills for people mostly doing blunter monitoring tasks (deskilling).

5.5 Get the priorities straight

This study illustrates developments in OSH conditions for Norwegian salmon farming workers, including noticeable differences between the OSH conditions at conventional and new concepts. For new concepts, some risks may be higher due to larger dimensions and forces, and more energy in the operations. Thus, emergency preparedness will require more resources and personnel moving forward (Bjelland et al., 2025; Thorvaldsen, Salomonsen, et al., 2023).

Basic safety research underlines the importance of prioritizing OSH – and thus devote the necessary resources and management facilitation (Rasmussen, 1997; Reason, 1997). While safety management in

conventional salmon farming is seen as reactive rather than preventative by some informants, the safety mindset described by informants working with the new concepts seems to be more proactive. New safety measures and solutions are implemented, resources are planned to avoid understaffing and to prioritize OSH when conflicts arise between protection and production.

Although safety management is taken seriously by the new actors, they still describe many of the same challenges as conventional concepts. As many new concepts have been in operation for a short time, it may look like routines and organizational structures are not always robust in stressful operations. OSH routines must provide protection when production requirements are high (Reason, 1997), but it seems that the potential of better safety management has not been fully realized.

This study also provides general learning points for safety research about how major changes in concepts, operations and organization can reduce risks, but also potentially increase unknown risks.

- New developments and actors have introduced proactive and creative safety management in an industry that traditionally has been reactive.
- Large investments and concepts have given attention to safety management but also introduced more risks and uncertainty.
- The improved risk handling and measures can potentially reduce the personnel's abilities to handle risk in the long run, due to the deskilling of competence needed to perform safe large operations.

6. Conclusion

This study has explored OSH at new salmon farming concepts in Norway. The new concepts have larger production units, increased dimensions, more complex operations and thus other hazards than those of conventional fish farms. More operations are now remote, so personnel are removed from known hazards in many operations. Although the new actors are eager to improve safety management, some of the changes may increase other risks, including poorer decision-making by deskilled operational personnel in operations with major risks.

In general, the study illustrates that investments in an industry can enhance safety management, but also bring about changes that require experience to understand and manage; otherwise, they may increase risks.

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