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# Risk dimensions of fish farming operations and conflicting objectives

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ABSTRACT: Operations at sea-based fish farms can be challenging, and several risk dimensions are of concern during operations. Sea lice represent a challenge for the fish farmers who are required to perform delousing when the infestation levels rice above a set value. Delousing operations are frequently performed and require the use of heavy machinery operated from service vessels moored to the net-cages. Operators are exposed to hazards that may cause severe injuries and fatalities. Escape of salmon, which is a substantial environmental risk, has occurred in relation to delousing operations. Chemicals used during the operations may cause negative environmental consequences. Other safety related issues are the fish health and welfare. In this paper, a delousing operation on a fish farm is discussed with respect to different dimensions of risk, and potential conflicting objectives are discussed.

## 1 INTRODUCTION

The operators on fish farm localities have to navigate and make decisions in an environment where their own safety is lined up against other factors, such as fish welfare and prevention of escape of salmon. The workplace is exposed to forces from the environment, such as waves, current and wind, and maintaining focus on safety is crucial in all operations. Authorities with different regulatory responsibilities require risk assessment of prevention of fish escape, environmental impact and fish welfare (Holmen et al., 2017). Identification of hazards and risk assessments are measures implemented to avoid accidents. Holistic and systematic risk management is a prerequisite for safe operations, however, the fragmented regulation might work against this (Utne et al., 2017).

Projects related to the evaluation of risks in fish farms have identified critical operations, such as lice counting, well boat operations and operations involving cranes (Sandberg et al., 2012). Technology, the physical working environment, work-load, work pressure and safety management are found to be among the factors influencing escape events (Thorvaldsen et al., 2015). External pressures on operations, such as time, costs and weather conditions also puts constraints on operations.

Lice infestations has become a major sustainability challenge in Norwegian fish farming, and has also become the main delimiting factor for future growth in the industry (Svåsand et al., 2017, Norwegian Ministry of Trade Industry and Fisheries, 2017). The fish farming industry in Norway uses up to NOK 4,5 billion in anti-lice measures (DN, 2017). Treatments to remove lice are decreed in regulations (Norwegian Ministry of Trade Industry and Fisheries, 2012), and has become an operation frequently performed in fish farms. Delousing is an operation where several factors identified as critical or risk-influencing are present, see Table 1.

In this paper, the first three risk dimensions are presented and compared with the purpose of identifying examples of potential conflicting objectives in the fish farming operation delousing. Conflicting objectives is an accident perspective, and highlighting consequences of the different pressures the human operators are exposed to in aquaculture, risk-reducing measures can be developed.

## 2 RISK DIMENSIONS IN A CONFLICTING OBJECTIVES' ACCIDENT PERCPECTIVE

The concept of conflicting objectives is described by Rasmussen's migration model (Rasmussen, 1997a). It explains how accidents may happen when decisions in an organization are made based on different objectives and constraints. One example is the decisions made by management to minimize costs, while operators may focus on making the operations as efficient as possible. These sometimes competing, or conflicting, objectives may eventually lead to a migration towards the boundary of a functionally acceptable performance. As the decisions are made local at separate levels, the side effects of the decisions may eventually set the stage for an accident (Rasmussen, 1997b). The operators can be seen to be at the sharp-end, close to the hazard sources, while management can be seen to be at the blunt end, removed from the hazards (Rosness, 2001, Rosness et al., 2010a).

Table 1. Risk dimensions present in the fish farming operation delousing. Adapted from (Yang et al., 2017).

| Risk dimension | General description | Relation to delousing operations |
|---|---|---|
| Risk to personnel | The Norwegian fish farming industry has one of the highest fatality and accidents rates when compared to similar industries (Aasjord, 2010). Accident statistics show that the fish employ ees are among the most exposed workers with regards to injuries and fatalities (Holen et al., 2017a). | Frequent use of safety critical equipment during delousing operations. |
| Risk to environment | The escape of salmon represents a hazard for the stock of wild salmon living in the rivers and fjords of Norway (Svåsand et al., 2017). The use of chemicals in delousing operations and on the net-cage to avoid fouling may affect the environment around the fish farm. Waste that accumulate under the fish farms due to fodder spill and organic matter and may have benthic impacts and on species living around the fish farm (Holmer, 2010). | Risk of net-tear is present during delousing operations. Medical treatment chemicals are released after operation. |
| Risk to fish welfare | Fish welfare in fish farms are under pressure due to sea lice and diseases (Hjeltnes et al., 2017). | Delousing operations require handling of the fish and may cause harm. The chemicals used in delousing may cause discomfort and wounds. |
| Food safety | Food safety is a general concern due to the accumulation of toxins in the fish meat. | Chemicals used for treatment of fish are not seen as critical for food safety (Norwegian Veterinary Institute, 2016). |
| Risk to material assets | Risk to material assets (e.g., net-cages, service vessels, workboats etc.) in fish farm operations may have severe economic consequences, mainly to the fish farm company. This risk dimension has not gotten much attention in the literature (Xue, Yang et al. 2017). | Structural damages of net during delousing may lead to escape of salmon which is a risk dimension already included. |

Safety is an emergent property of a system and risk should be considered in a systems perspective where all factors that can influence safety, should be analyzed. Control can be made by increasing the safety margin, increase awareness of the boundary, or make the boundaries explicit. Making visible the limits on acceptable risk by establishing criteria for critical decisions or other ways of establishing clear lines as to when the safety margin is small should encounter challenges with conflicting objectives. Managers should also communicate openly about the existence of conflict of interest (Rosness et al., 2010b).

Fish farming is an industry dealing with production of livestock, thus requiring knowledge about biology, welfare, and diseases. In addition, operations are increasingly resource demanding and large production equipment requires special expertise for safe handling. The fish farms are mainly placed in the fjords where the operations may impact the fauna and wild animals living around the fish farm. These are all risk dimensions of concern for the operators at the sharp-end, and in some situations trade-offs between the risk dimensions must be made. In this paper these are seen as conflicting objectives. An example of a situation where operators are faced with having to choose between prioritizing risk objectives is provided by Størkersen (2012). The operators have to choose between fixing a net cage damage immediately after discovery, or use valuable time to provide the appropriate safety equipment to do the repair according to safety procedures. In the case presented, the operators do not hesitate to improvise and make the repair without the required safety equipment. Thus, the risk of escape is reduced, while the operators face a greater personal risk by down prioritizing their own safety (Størkersen, 2012).

The management at the blunt end is also making choices that affect the risk in operation, by allocating resources, like personnel, equipment and timeslots to operations. Management decisions influenced one of the biggest single escape event in Norway, which happened in relation to a delousing operation in 2011 where 176 000 salmon escaped (Soknes, 2012). The delousing operation had been ongoing

for two continuous days in order to finish the operation as quickly and efficiently as possible. The company later claimed that the responsible operator was disloyal to the company when breaching procedures to get the job done. However, a court case ruled that the employee had loyally tried to fulfill the management's expectations and that there had been a great time pressure on the employees, and no willingness from the company to compensate economically for extra personnel (Soknes, 2012).

Time pressure is a risk-influencing factor mentioned by personnel at fish farms in relation to both escape events, fish welfare and personnel safety (Thorvaldsen et al., 2015, Hjeltnes et al., 2017, Fenstad et al., 2009). Time pressure is not only created by allocation of resources by management, but also unforeseen weather changes puts this constraint on operations.The regulation of the fish farming industry is characterized by being fragmented and the authorities have developed separate regulations to ensure the different values being protected (Holmen et al., 2017). Fish farmers state that the focus in planning for safety in operations will be towards the area were they experience pressure from the authorities (Skjærvik, 2017). In line with Rasmussen's framework of distanced decision-making, some unforeseen consequences might be the result. For example, the strict regulations on delousing according to infestation levels may lead to both unsafe situations concerning escape and reduced welfare for the fish.

## 3 THE DELOUSING OPERATION

### 3.1 *Anti-lice measures*

The sea lice, or salmon lice, is a parasite, which only have salmonids as hosts. The last five stages of the life cycle of the sea lice are parasitic to the salmon, when it feeds of the mucus, skin and blood. The sea lice may cause fish welfare problems both to farmed and wild salmonids, and may ultimately cause fish death. The sea lice has become a major issue in the fish farming industry where large outbreaks of the parasite is made possible by the high density of salmon in the fish farms along the coast. The sea lice is sensitive to temperature, and infestation levels change according to the season; the lowest levels are registered in the spring and the levels increase during summer and fall (Svåsand et al., 2017). This have led to frequent delousing in periods of the year.

As the sea lice mainly lives in the higher levels of the sea some preventive measures to sea lice have been developed, e.g., a skirt placed around the net cages with a depth up to 3 meters preventing the sea lice to enter in the area where the salmon are (Lien et al., 2014). The skirts around the net are the most used preventive measure (Svåsand et al., 2017). Also a "snorkel"-solution, where the fish are held in an semi-enclosed net cage, only with access to water air through a "snorkel" with a diameter around 6 meters (Stien et al., 2016). In 2017 over 27 million wrasse was captured, mainly used for delousing purposes in fish farming (Directorate of Fisheries, 2017).

The main mode of combating the sea lice have been medicinal products. These can either be introduced to the fodder, or the salmon are exposed to the medicament in bath-treatments. In bath treatments, the salmon are exposed to medicinal products added to the seawater after the salmon is gathered in an enclosed area, in either a well vessel or using a tarpaulin around the net cage. The bath treatments require major resources and is one of the most demanding operations that is carried out in fish farming.

In addition to the bath-treatments, some new technologies have been developed to remove sea lice from farmed salmon. These methods have been developed mainly due to resistance in the salmon lice of the medicaments used. The new treatments use mechanical aids, such as water jets, higher temperature and brushes. These new methods are seen as the main cause in the large drop in prescribed anti-lice treatment medicaments from 2015 to 2016. There is a concern that the new methods might be a risk to fish welfare, and that they have not been sufficiently tested for welfare before they have been put to use (Hjeltnes et al., 2017). In addition, signs of possible resistance to these new anti-lice treatments have been discovered.

### 3.2 *Steps of a bath treatment operation*

Figure 1 show the steps of a fish farm operation using tarpaulin. This approach is representative for all methods of delousing, only the step "Perform delousing" differs according to the method and technologies used.

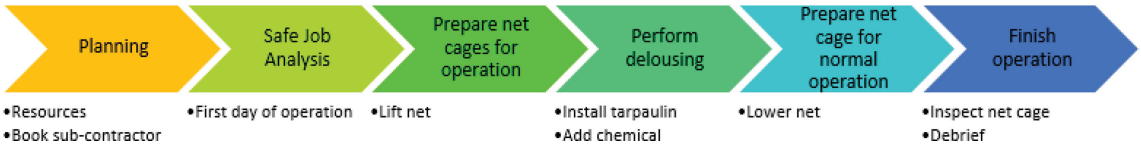


Figure 1. Steps of a delousing operation using tarpaulin.

- Planning

Delousing must be carried out when the critical level of lice is reached. The operation is planned by the operations manager on the fish farm, sometimes in cooperation with higher level onshore area managers. The operations are in most cases performed by or in co-operation with service providers who have both required equipment and expertise.

- Safe Job Analysis (SJA)

Most fish farmers conduct a preparation meeting the day the operation starts. An integral part of this meeting is to perform a SJA, where hazards in the operation are identified and responsibilities for tasks during the operation are assigned.

- Prepare net cage for delousing (Lift net)

It is necessary to make the volume of the net cage smaller so that the fish is easily accessible in the upper layers of the sea. Lifting is demanding and time-consuming, and requires the use of crane and winches from work vessels. If a well vessel or a type of barge is used in the treatment, a "crowding" of the fish is also necessary. This is done by using an extra net to push the fish together in an even more confined area.

- Perform delousing

Bath-treatment are either performed with tarpaulin in the net cage or in a well vessel. New types of mechanical treatments are performed on specialized barges.

- Prepare net cage for normal operation (Lower net)

After the treatment, the fish is put back in the net or the tarpaulin is removed, depending on the type of treatment. Then the net needs to be lowered to its normal position. This is done in a reverse manner to the lifting of the net. Careful lowering of the net and ropes are necessary to avoid any damage.

- Finish operation

After the operation is finished, an underwater inspection should be made by either divers or a ROV. Debrief-meetings will ensure that any adverse events during the operation are discussed and subsequent changes implemented in safety management systems.

## 4 RISK DIMENSIONS OF DELOUSING OPERATIONS

In this section, the three first dimensions of risk in Table 1 (Yang et al. 2017) are presented and discussed for the delousing operations.

### 4.1 *Risk to personnel*

Delousing operations are demanding operations where the operators on fish farms are exposed to several hazards. Most of the delousing techniques require use of cranes when preparing for the operation. In accident statistics from the fish farming industry, the use of cranes are found to contribute to several of the blow by object and entanglement injuries (Holen et al., 2017a). Work operations are also an increasing contributor to fatalities in the fish farming industry (Holen et al., 2017b). As service vessels are an important part of the operation, also man over board accidents is in important risk to consider. In addition, the chemicals used in delousing operations may present a hazard to the operators. In some delousing operations, extra oxygen is used, and explosions may happen.

### 4.2 *Risk to the environment*

In general, two types of hazards to the environment should be assessed in relation to delousing operations; (i) the effects from escaped farmed salmon, and (ii) the release of treatment chemicals, which may have an effect on organisms around the fish farms.

#### 4.2.1 *Risk of escape*

The main causes to escape from fish farms are due to structural failures including net tearing. Net tearing can happen during operations and from abrasion from related components (Jensen, Dempster et al. 2010). Abrasion from the sinker tube chain is the most common cause for net tearing, while handling of net weights, including the sinker tube is the second largest cause (Føre and Thorvaldsen, 2017). Handling of net weights must be done in all delousing operations, as part of the preparation before the operation, and after the operation has been completed. Organizational factors influencing escape events are found in Thorvaldsen, Holmen et al. (2015).

The consequences of escaped salmon are related to introgression of genes and the spreading of diseases, which both may influence the wild salmon. Introgression of farmed salmon genes is unwanted because of the genetic differences in farmed salmon and wild salmon (Taranger et al., 2015). The long term consequences of introgression may lead to "changes in life-history traits, reduced population productivity and decreased resilience to future changes" (Glover et al., 2017).

#### 4.2.2 *Risk of treatment chemicals on surrounding environment*

The medical chemicals used for bath treatment of sea lice may affect other animals, especially crustaceous animals as the sea lice belongs to this type of animals. The chemicals used for bath treatments are Azametifos, Deltametrin, Cypermetrin and Hydrogrenperoxid; the three first chemicals are mainly used in tarpaulin treatments, while the last

is used in well vessels. When the bath treatment is made with tarpaulin, the chemicals are directly released into the sea at the fish farm; when well boats are used the chemicals can be transported away (Svåsand et al., 2017). The different chemicals have different levels of toxicity, where Deltametrin have been shown to be very toxic for some non-target organisms, such as plankton, and may also be bound up in seaweeds. Hydrogen peroxide have the least effect on organisms in the surroundings of the fish farm (Svåsand et al., 2017). In a five-year study of effects of sea lice medicine to the receiving environment in Scottish sea lochs, no long-term effects could be found (Scottish Association for Marine Science, 2005). Chemical release in the case of vessel capsizing may also be a risk.

### 4.3 *Risk to fish welfare*

Fish welfare is affected by the salmon louse itself and the anti-lice treatments carried out to remove the lice. Normally the damage to the farmed salmon is not high because treatment is required before a critical number of lice is reached (Svåsand et al., 2017, Norwegian Ministry of Trade Industry and Fisheries, 2012). However, substantial injuries in some areas where the salmon lice infection pressures have not been possible to control have been reported (Hjeltnes et al., 2017). The larger wounds caused by sea louse may lead to dehydration, electrolyte balance and increased influence on physiological functions with the fish (Svåsand et al., 2017).

Anti-lice treatment represents a significant negative welfare challenge to the fish (Hjeltnes et al., 2017). Especially handling and crowding of fish, which is done in relation to the treatment, will have an impact on welfare of the fish. The stress and fear-levels increase in the fish during these operations and if the fish is weak, heart failure may occur. Open wounds, scale and mucus-loss and stress are factors caused by handling which might also increase the risk of other infections in the fish (Svåsand et al., 2017). The chemicals used in treatment may be overdosed and give toxic effects. Observed fish behavior during delousing operations may indicate that the fish experience the treatment chemicals as uncomfortable (Oppedal et al., 2011).

Bath treatments have been the primary method of delousing, but new methods and technologies, which does not use chemicals, are increasingly in use, mainly due to resistance of chemicals in the salmon louse. Mechanical delousing using heated water, water jets or a combination of water jets and brushes are reported to give welfare issues related to reduced appetite, eye injuries, reduced mucus production and poor skin health, amongst others. These new methods of anti-lice treatment are of great concern to fish welfare as they are not sufficiently tested for effectiveness and welfare (Hjeltnes et al., 2017). Heated water treatment has caused mass-fatalities of salmon (Heraldscotland, 2016).

### 4.4 *Conflicting objectives of the risk dimensions*

Some examples of how each risk dimension may influence the others during the delousing operation are presented below. Especially, risk to personnel safety, risk of escape, and risk to fish health may come in conflict. All these dimensions are also under the constraints introduced by management decisions like allocation of resources, such as personnel, equipment and timeslots to operations.

#### 4.4.1 *Prioritizing personnel safety*

Personnel safety has been given increasing focus in the fish farming industry. Major hazards for personnel are especially present during operations using heavy machinery. For delousing operations, this type of machinery is used in preparation of the delousing, and after the operation when net is lifted and lowered. Handling of the net also involves hazards with regards to tearing of net and following escape. In stressful situations, due to limited attention span, there could be a need to focus on one of the risk factors. Situations where focusing on personnel safety may cause higher risk with regards to escape may also occur after operations when inspections of the net cages should be done to ensure that the nets have been correctly lowered. Inspections by divers or cameras must be done so that potential holes caused during operation are discovered. In cases where there may be risk of injuries because of, e.g., weather conditions, personnel safety must be prioritized over prevention of escape.

Stopping operation too soon or too late in cases of risk to personnel may cause the delousing treatment not to work adequately. The operation must then be repeated later, which represents an extra strain to fish welfare, which must undergo handling again in a short time. If operation is not completed the net may not be lowered in between operations which also means that the fish must be kept “crowded”.

#### 4.4.2 *Prioritizing fish welfare*

Fish welfare has traditionally been given high priority. Fish welfare is important to management as it affects earnings. Cases when fish welfare may influence personnel safety or prevention of escape during operations, may occur if delousing with tarpaulin must be abruptly stopped due to, e.g., too low oxygen levels in the net cage. Stressful

situations and a focus on fish welfare may lead to hazardous situations by personnel. The choice of delousing methods may also have an influence on the fish welfare. Bath-treatments with tarpaulin include some more hazardous tasks using crane compared to bath-treatments in well vessels. Whereas well vessels may include more welfare issues due to "crowding" and pumping of the fish in and out of the vessel.

#### 4.4.3 *Prioritizing prevention of escape*

Prevention of escape is a major focus of the fish farming industry. This focus may also have been at the sacrifice of personal safety in procedures and risk assessments. An inadequate focus on hazards that may cause personnel injuries when planning operations and in safe job analysis performed before delousing may contribute to accidents.

If a hole in the net is discovered, fish may be kept crowded longer than normally to keep the fish away from hole in the net. This will be at the expense of fish welfare.

#### 4.4.4 *Prioritizing limited consequences for environment*

When using well vessels for delousing operations, chemicals used during operations may be transported out of the fjords into designated "drop zones". The choice of using well-vessels may have an influence on fish welfare in operations. Some of the new delousing methods do not use chemicals and, in this regard do not represent a challenge to the environment. Emissions to the environment of the chemicals used in delousing operations are an integrated part of the operation, especially when using the tarpaulin. The consequences of the release of chemicals into the fjords is a controversial issue between the stakeholders.

## 5 DISCUSSION

Several risk issues are present during fish farm operations, and delousing is no exception. Accidents, such as escape, serious personal injuries and major fish deaths, have happened in relation to the activities in delousing operations. In the accident perspective of conflicting objectives, one of the measures towards avoiding accidents is to make visible the limits of acceptable performance. It is important to assess how prioritizing one risk issue may affect other risk aspects and dimensions. During delousing operations both personnel safety, fish welfare and fish escape are concerns, which require attention. It is not possible to eliminate the conflicting objective as they, in today's methods available for delousing, are inherent in the operation. However, means to avoid accidents due to conflicting objectives are to highlight the conflicts themselves and the possible consequences of giving priority to one aspect in operations. Visualizing the different risk dimensions, which may give rice to hazardous situation, gives an opportunity for operators and management to gain awareness of possible hazards in the operation.

Possible risk mitigating actions could be to assign some operators the main responsibility to follow whether one risk issue is given an unbalanced focus. The different steps of the operation may also be more hazardous with regards to one type of risk. For example, the beginning of preparation of the net cage is hazardous related to tearing of the net, while the last part of preparation may be more hazardous to personnel injuries because of excess chains suspended from the crane. In addition, correct lowering of the net after operation is a critical part of the operation concerning escape events.

Risk avoidance of some of the measure might also have mutual positive effects. One example of this is to not starting delousing treatment in harsh weather, as this might present hazards to both personnel and fish welfare (Størkersen, 2012, Fenstad et al., 2009).

In almost all situations during operations where one risk issue might be prioritized over a different one, management decisions, such as time pressure, costs and weather may influence the decisions made during an operation. Stress due to time limits and limited resources will affect how choices are made, and violation of procedures might be done if that is what seems most rational in the moment. When evaluating how risk mitigating measures might work, one should be aware off the mechanisms of the socio-technical system where different actors will make decisions according to their respective constraints and options, and that some interpretation of rules will be made at lower levels of the organization (Rasmussen, 1997b). Within the aquaculture company, the operators are in the sharp-end in close proximity to the hazard, and they make decisions within different frames of what the land based organization with higher level of authority and distance to the hazard do. Without the possibility of always seeing the whole picture decisions on both ends are made on "local rationality". Often, it is explicitly said that safety should be prioritized, but tacitly opposite messages are sent through planning, follow-up and resource allocation. Measures should be implemented in and continuously monitored by the management systems to ensure that safety is not compromised.

In this paper, the immediate risk issues that arise during an operation due to conflicting objectives has been in focus. In a broader perspective, other risk issues would also be relevant to consider with regards to conflicting objectives such as resistance

of sea lice to the different treatments and the influence of regulations on the different risk issues. The decisions made on higher level may have more impact to the risk picture, than the decisions made by operators during operations. The regulations that specifies the limits for the acceptable lice level may challenge fish welfare as it leads to frequent delousing (Hjeltnes et al., 2017). This is seen as a challenge to the welfare and in some cases the levels of lice might be more acceptable to welfare than performing repeated treatments which cause strain and stress to the fish. Repeated delousing operations will also increase the possibility of escape due to handling of the net.

## 6 CONCLUSION

Sea lice is a major challenge to the fish farming industry and delousing is decreed by the authorities. The delousing operation involves risk dimensions with regards to personnel safety, the environment and fish welfare, all issues including severe consequences. Conflicting objectives may arise during the operation. Prioritizing one risk dimension at the expense of others may lead to situations, such as: (i) focusing on personnel safety may hinder the discovery or repairing holes in the net, or (ii) operator stress to finish operation due to fish welfare, may cause hazardous situations for personnel. Higher-level management decisions also influence the risk during operations through, e.g., timely allocation of resources. Unforeseen accidents may happen if conflicting objectives are not visible to management and operators, and they should be openly discussed to ensure safety in operations.

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