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Analysis of current ROV Operations in the Norwegian Aquaculture

Reducing Risk in exposed Aquaculture
Operations

Anne Jieli Louise Solem

Marine Technology
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Supervisor: Ingrid Bouwer Utne, IMT

Norwegian University of Science and Technology
Department of Marine Technology

NTNU
Faculty of Engineering Science
and Technology
Department of Marine Technology

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Trondheim, July 2017

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Preface

This master thesis is submitted as a completion of the master's education in Marine Technology at the Norwegian University of Science and Technology (NTNU) in Trondheim. The work has been performed by the master candidate alone, at the Department of Marine Technology (IMT) during spring semester of 2017, and with Professor Ingrid Bouwer Utne as main supervisor.

Background for the thesis is that the Norwegian aquaculture industry wants to expand into more exposed areas, due to lack of space along the coastline. These areas are characterized with harsher environmental conditions that will create operational challenges for the service workers, and influence how and when operations can be conducted. The master thesis is a continuation of the project thesis with the same title, *Analysis of ROV operations in aquaculture* conducted during the autumn semester of 2016.

The overall objective is to further continue the analysis and provide valuable inputs about the current use of ROV operations, and diving operations in the aquaculture industry. Focus areas are operational requirements, procedures and documentation. The results will further be used to assess the potential for risk mitigation for operators by increased use of ROVs, by considering to what extent ROVs create better solutions by assessing strengths, weaknesses, challenges and costs compared with divers.

In order to gain a genuine understanding of today's situation, a literature study has been conducted. In addition, information has been collected through observations, and conversations and interviews with different stakeholders.

This work has been carried out as part of the Reducing Risk in Aquaculture project, a research project affiliated with the Centre for Research-based Innovation (SFI) Exposed Aquaculture Operations.

The Norwegian Research Council is acknowledged as the main sponsor of project number 254913.

The thesis is comprehensive, and some pages are therefore left blank intentionally to increase readability.

Trondheim, 2017-07-24

Anne J.L. Solem

Anne Jieli Louise Solem

Abstract

The Norwegian aquaculture is already considered to be one of the most dangerous occupations when it comes to risk, and the risk is likely to be amplified as the industry wants to expand and utilize more exposed areas. These areas are characterized by more extreme and unpredictable weather conditions, including higher wave heights and stronger currents, which challenges the safety and efficiency of current operations. Several inspection, maintenance and repair (IMR) operations today are highly dependent on manual labour, which leads to close human interactions that put the workers at risk.

This master thesis addresses how increased use of ROV operations can help reducing the risk in exposed aquaculture operations. The main objective is to provide knowledge about the current situation for ROV and diving operations in the Norwegian aquaculture. The purpose is to gather information from the industry itself, focusing on why and how increased use of ROVs will help mitigate the risk, by assessing strengths, weaknesses, challenges and costs compared with divers. Information has been gathered through observations, interviews and conversations with different stakeholders, resulting in a very comprehensive result part covering several topics within the area of interest. The results where then assessed in light of the purpose.

The thesis confirms that some of the most detailed diving operations need to be solved by divers, and that ROV will probably never be a 100% able to replace them. Furthermore, the thesis confirms that the harsh environment form the greatest challenges.

An overall conclusion is that increased use of ROVs will create a positive chain reaction against reduced risk and increased efficiency. It will mitigate the human risk by taking over several diving operations. Operational efficiencies are also believed to increase, as a ROV is able to move faster than a diver in the water. Although researchers and manufactures are working hard to find new and better solutions, the thesis confirms that

there are still a lot of challenges related to the use of ROVs for various IMR operations that needs to be solved to mitigate the increased risk in these areas.

Sammendrag

Norsk havbruk er i dag ansett for å være en av de farligste næringene å jobbe i, da flere av dagens inspeksjons-, vedlikeholds- og reparasjons (IMR) operasjoner krever høy grad av manuell håndtering. Dette skaper stor fare for menneskelig sikkerhet ved utfordrende situasjoner. På grunn av mangel på nok plass i fjordene ønsker næringen å utnytte seg av de mer eksponerte områdene lengre ut. Disse områdene karakteriseres av mer uforutsett vær og ekstremvær som blant annet betyr høyere bølger og sterkere strømmer. Disse vil påvirke dagens operasjoner og øke risikoen for arbeidernes sikkerhet.

Denne masteroppgaven tar for seg hvordan økt bruk av ROVer kan bidra til å redusere risikoen for operasjoner utført i eksponerte områder. Hensikten med oppgaven er å levere kunnskap om dagens situasjon for ROV- og dykkeoperasjoner, ved å samle inn data fra industrien. Fokusområder er hvordan og på hvilken måte ROVer kan redusere risikoen ved å vurdere styrker, svakheter, utfordringer og kostnader sammenlignet med dykkeoperasjoner. Data har blitt samlet inn gjennom observasjoner, intervjuer og samtaler med ulike arbeidere. Dette har resultert i en omfattende resultatdel som gir informasjon om flere aktuelle temaer. Videre ble resultatene diskutert ut i fra nevnte fokusområder.

Masteroppgavens resultater og vurderinger kan bekrefte at noen av de mest detaljerte dykkeoperasjonene i dag trolig aldri vil kunne bli 100% erstattet av en ROV. Videre bekrefter oppgaven at det uforutsette været utgjør den største utfordringen ved dagens operasjoner.

En samlet konklusjon er at økt bruk av ROVer vil skape en positiv kjedereaksjon mot redusert risiko og økt effektivitet. Økt bruk vil redusere den menneskelige risikoen ved å ta over flere av dagens dykkeoperasjoner og på den måten skape større menneskelig avstand til operasjonen. Videre antas driftseffektiviteten å øke, da en ROV er i stand til å bevege seg raskere i vann enn en dykker. Selv om forskere og produsenter jobber

hardt med å finne nye og bedre løsninger, bekrefter masteroppgaven at det fortsatt er mange utfordringer knyttet til bruk av ROV for ulike IMR-operasjoner som må løses for å redusere den økte risikoen.

Acknowledgment

First I would like to thank my main supervisor Professor Ingrid Bouwer Utne, of Department of Marine Technology, at the Norwegian University of Science and Technology (NTNU). Thank you for always having the door open, and for valuable guidance through the work with both the project thesis and the master thesis. Also thank you for reading through before delivery.

Then I would like to express my gratitude to PhD Candidate Ingunn Marie Holmen. Thank you for useful start-up help, and sharing of knowledge. Also thank you for reading through my thesis, and for arranging the first field trip.

Further I would like to thank researcher Per Rundtop, and head of research for SFI Exposed, Hans Vanhauwaert Bjelland, both from SINTEF Ocean. Thank you for introducing me to the topic of the thesis: *Exposed aquaculture* and how ROVs are used today.

Thanks to all the companies that have participated in my survey, for sharing their precious time, and valuable knowledge through conversations and interviews. A special thanks to the three companies who shared their working day with me in a most generous way.

Finally, I will express my very profound gratitude to my family and study friends, for all the love and support. This thesis is a result of five years that would not have been possible without them. Thank you.

A.J.L.S.

Abbreviations

AGD	Amoebic Gill Disease
AUV	Autonomous Underwater Vehicle
CEO	Chief Executive Officer
COO	Chief Operating Officer
CTO	Chief Technology Officer
EPA	Employment Protection Act
EQS	Extend Quality System
FNC8	Flying Net Cleaner 8
HEQ	Horizon Equipment
HB	Horizon Budget
HMT	Horizon Management Tool
HO	Horizon Optimizer
HP	Horizon Planner
HRS	Horizon Reports Studio
HS	Significant wave heights
HSE	Health, Safety, and Environment (Norwegian: HMS)
ICT	Information and Communication Technology
IO	Integrated Operations
IMR	Inspection, Maintenance, and Repair

kW Kilowatt

MPI Multi Pump Innovation

NOK Norwegian kroner

OSE Oslo Stock Exchange

PhD Doctoral education

RONC Remote Operated Net Cleaner

ROV Remotely Operated Vehicle

SFI Centres for Research-based Innovation

SHE Safety, Health and Environment

SJA Safe Job Analysis

UHF Ultra High Frequency

VHF Very High Frequency

WEA Working Environment Act

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Chapter 1

Introduction

This chapter introduces the master thesis with some motivational aspects, problem statement and purpose, objectives, limitations, and target group. A brief outline of the different chapters is also presented at the end.

1.1 Motivation

The ocean covers around 70% of the Earth surface (Holmer, 2010), which makes the possibilities of expansion available. The aquaculture is currently farming a total of 580 groups of species around the world, and remains an important source of food, nutrition, income and employment for hundreds of millions of peoples. Approximately 73.8 million tonnes were harvested in 2014, including finfish, molluscs, crustaceans, and other aquatic animals such as frogs. Some by-products may be used for non-food purposes, but almost everything else goes to human consumption (FAOSTAT, 2016). Currently fish ensures about 6.5% of all protein for human consumption (TWB, 2013).

The need for healthy food is increasing as the world population growth increases (Holmen et al., 2017b). It is a global challenge to produce sufficient amount of food, and there are no doubt that fish farming will play an important role in satisfying that need (Bjelland et al., 2015; Utne et al., 2015). The World Bank projects states in their report that the global fish supply will rise to 187 million tons by 2030, and that the population in 2050 will be around 9 billion (TWB, 2013). That means the fish farming industry needs to expand to meet the human demand (Naylor et al., 2005).

The aquaculture industry is growing each year, and as Norway is the dominant producer and exporter of Atlantic salmon worldwide (Holmen et al., 2017a), the Norwegian interest is only increasing. This can be noted on the larger size of the new vessels and facilities (Fenstad et al., 2009).

Humans are driven by the desire to expand and further develop better solutions for the industry to grow. Currently, there is an increased focus on how to utilize production sites with more exposed and remote waters. The reason for that is lack of coastal space, and because these areas are believed to result in several advantages for the environment, and the fish. Advantages such as improved environmental sustainability, better land use, and value creation (Holen et al., 2012; Holmen et al., 2017a; Holmer, 2010). The Norwegian aquaculture industry shows great interest in utilizing these areas (Bjelland et al., 2015), as the aquaculture have evident needs that indicate that the industry requires expansion (Bjelland et al., 2015; Bjelland, 2017). Figure 1.1 shows a typical fish farm facility located in a sheltered fjord (Sperre, 2016).

Figure 1.1: Fish farms in sheltered fjord (Sperre, 2016).

Technological development will according to the United Nation's Fisheries and Agriculture Organization, play a major role for future industry expansion. The Norwegian industry has the potential of farming 5 millions tons of fish per year by 2050, if the developments can cope with the production and environmental challenges (Bjelland et al., 2015).

The industry has not had any production growth for the last four to five years, due to lack of good production sites, in addition to lack of good enough technological solutions and operational changes. Currently, there are several challenges by moving into more exposed areas, challenges such as harsh and unpredictable weather that will require new solutions. That is where automation comes in. Automation and more remotely controlled operations will increase the safety for the workers, and most likely also make the operations more efficient (Bjelland et al., 2015; Exposed, 2017; Sund, 2016).

Researches believe that change will come, because compared to earlier, fish farming has been given a different position in society than it had before, both publicly and among engineers. Consciousness has improved and the industry is more open to change (Bjelland, 2017; Holen et al., 2012).

Currently, the aquaculture industry is the second most risky occupation in Norway after fisheries (Størkersen, 2011; Utne et al., 2015), as most technologies and operations are highly dependent on manual labour and close human interactions with either the process equipment, or cage structure (Utne et al., 2015). Examples are typical inspection, maintenance and repair (IMR) operations like net repair and net cleaning (Sund, 2016). Examples of current accidents are drownings, electrocution, falls with serious head injuries, or poisoning by chemicals (Sund, 2016).

Until now it has been a huge focus on food production and structural safety to prevent fish escapes, and a limited focus on health, safety, and environment (HSE) issues in the aquaculture. One result of that is that fish farm structures now satisfy more stringent requirements (Sund, 2016). But moving towards more exposed areas will increase the operational risks, and emphasize the need for more remotely and autonomous operation options, because of the area characteristics (Sandøy, 2016). These options will most likely contribute to positive industrial production growth, and be more cost-efficient over time (Bjelland et al., 2015; Holmen et al., 2017b). Another advantage is that they will increase the operational safety for the workers, by reducing the manual operators workload (Utne et al., 2015).

Increased use of remotely operated vehicles (ROVs) are one way to make the operations safer for the workers, as they allows for greater distance between the workers and the risky situations (Rundtop, 2017). This is the foundation of this master thesis.

1.2 Problem statement and purpose

The overall problem statement is the analysis of current ROV operations in Norwegian aquaculture, with respect to operational requirements, procedures and documentation. The purpose is to gather information from the industry itself, and present their point of view on moving fish farming into more exposed areas, especially when dealing with ROV operations compared to diving. The information will be collected through observations and interviews. It will further be used to investigate the potential for risk mitigation for operators and increased fish farm productivity, by increased use of ROVs, by considering to what extent ROVs create better solutions by assessing strengths, weaknesses, challenges and costs compared with divers.

The work aims to provide the industry with valuable knowledge that can help further mapping of today's situation around diving and ROV operations. ROV operations are the main focus, but diving is also considered important due to the discussion part about whether ROVs create better opportunities or not for the future, compared to divers. This will help covering the gap between the current performance and capabilities of divers, and the current and future performance of ROVs. It will also help identify necessary improvements related to ROV usage.

1.3 Scope of work

1.3.1 Objectives

The main objective of this master thesis is to provide knowledge about the current use of ROV operations and diving in the aquaculture industry. The focus is to present the stakeholders points of view as detailed as possible when it comes to relevant information related to diving- and ROV operations. The lists below show the intended industry and research objectives. Industry objectives are what the master thesis intends to bring into today's industry, while research objectives are what will be conducted.

Industry objectives:

- Cover knowledge gaps between theoretical and practical implementation of diving and especially ROV operations today, by presenting information gained directly from industry workers.

- Enable safer working environment for service workers offshore.
- Provide information to strengthen effective and profitable operations at exposed fish farming sites.

Research objectives:

- Expand and further develop knowledge about current diving and ROV operations in aquaculture, focusing on when, why, how, and challenges.
- Assess the expected frequency of ROV operations in future exposed fish farming, as a basis for feasibility studies of, for example, different launch and recovery solutions.
- Gather information about operational costs for diving and ROV operations and discuss whether increased use of ROVs are beneficial or not due to safety, improved operational efficiency and cost savings.

1.3.2 Limitations

The master work is limited in time and extent, which means that certain decisions had to be made. For instance will this thesis only consider the Norwegian aquaculture, meaning that all involved companies have offices in Norway. Section 6.2 in chapter 6, page 104 provides recommendations for work that can be continued to cover the topic beyond this thesis limitations.

Working within the aquaculture industry requires cooperation between different parties. Since this thesis is about ROV operations, and whether they create better or less good solutions, fish farm companies, service companies, and fish farm equipment producers have been contacted to be able to cover the three main points: Needs, feasibility and opportunity.

The purpose was mainly to ask the different companies about their point of view on moving fish farming into more exposed areas since they all have their respective responsibilities. Since the industry is quite busy, combined with limited time for data collection, it can be seen in section 3.4.2, page 42 that the fish farm companies are not that well represented compared to the others. Still, this has not been considered a major limitation, as service companies have been the most important companies to reach.

1.4 Target group

The master thesis will be interesting for those doing research on exposed aquaculture, and also other involved companies. The target group is in general everyone interested in the topic. Even though the main topic is about ROVs, the result part is quite broad. Some people, due to their background and experience will maybe not find everything as interesting or new. The thesis is written for everyone, independent of background or whether they have read the project thesis or not. All necessary information related to this thesis, is provided in this thesis. Abbreviations will be used, and they will all be described the first time. A complete list of abbreviations is provided after the acknowledgment.

1.5 Outline

The master thesis has a structure similar to common reports and thesis, and it is quite straight forward. To make the overview better, each chapter starts with a short introduction that introduces the chapter's content.

Table 1.1 gives a brief description of the contents of the chapters as well as appendix.

Table 1.1: Structure of the master thesis.

CHAPTER	DESCRIPTION
Chapter 1	The *Introduction* chapter introduces the master thesis by presenting some motivational perspectives, problem statement and purpose, scope of work, and target group. The chapter ends with a brief outline of the thesis.
Chapter 2	The *Theoretical Background* chapter provides the theoretical basis needed to understand the discussion of the research, such as the Norwegian aquaculture today, the meaning of exposed, general information about divers, ROVs, and typical IMR operations.
Chapter 3	The *Methodology* chapter describes and justifies the choice of methods used in the thesis. It explains how they have been used, benefits and weaknesses.
Chapter 4	The *Results* chapter presents the information collected from the different companies through conversations, interviews and fieldwork. Information related to ROV operations makes a large part of this chapter, since the overall objective is about ROVs.
Chapter 5	The *Discussion* chapter discusses different angles based on the objectives presented in chapter 1, the theory presented in chapter 2, and the results from chapter 4.
Chapter 6	The *Concluding remarks* chapter closes the thesis by presenting the main conclusions and recommendations for further work.
Appendix	The *Appendix* chapters provide additional information extracted from the thesis. This is useful extra material, but not considered decisive for the master thesis coherence.

Chapter 2

Theoretical Background

The chapter consist of various sections that provides the theoretical background needed to understand the discussion of the research in chapter 5.

2.1 The Norwegian aquaculture

The Norwegian aquaculture started to produce Atlantic salmon in 1970 (Utne et al., 2015), and in 2013 they had achieved a production of 1.3 million metric tons of fish, with an export value of 39.8 BNOK (Exposed, 2017). The potential value creation is estimated to be 119 BNOK and 238 BNOK for 2030 and 2050 respectively (Bjelland et al., 2015). In Norway there is about 4000-5000 people working within different parts of the aquaculture industry, which now has become a leading export industry. In according to Bjelland et al. (2015), fish farming has the potential of a five-fold increase of production during the next 35 years that will create valuable job opportunities, economical benefits and production values (Thorvaldsen et al., 2013a).

Current farming focus is on Atlantic salmon and trout (Thorvaldsen et al., 2013a), and today's sea cage designs are either square, rectangular or circular. The size of the square and rectangular cages vary between 20-40 m sides, and 20-35 m depth, while the circulars vary between 90-157 m in circumference and 15-48 m depth. Volumes of these cages range from 20,000-80,000 m^3. The difference between these designs is that the square cages and rectangular cages are typically clustered together as a steel platform with 4-28 cages. The circular cages can be 6-12 cages arranged in a mooring grid, see figure 2.1, with single or double rows with space between each cage (Jensen et al., 2012). Other species that are being farmed are cod, halibut, mussels, and shellfish (Utne et al., 2015).

Figure 2.1: Circular cages clustered together (Bjelland et al., 2015)

2.2 Exposed aquaculture in Norway

There are fish farm areas today that are not in use, because the sites are too risky to operate on (SINTEF, 2015). The term *exposed* is according to head of research for SFI Exposed Bjelland (2017), hard to define. There are no specific formal definition, but Holmer (2010) show in their review a table that presents some differences between coastal farming, off-coast farming, and offshore farming. Offshore farming can be linked to exposed areas and the table is presented in figure 2.2 under.

	Coastal farming	Off-coast farming	Offshore farming
Physical setting	<500 m from shore <10 m water depth Within sight of shore users	500 m to 3 km from shore 10 to 50 m water depth Usually within sight	>3 km from shore >50 m water depth On continental shelf Not visible from shore
Exposure	Waves <1 m Local winds Local currents Strong tidal currents Sheltered 100 % accessibility	Waves <3 to 4 m Localized winds Localized currents Weak tidal currents Somewhat sheltered >90 % accessibility	Waves up to 5 m Ocean winds Ocean swell No tidal currents Exposed >80 % accessibility
Legal definitions	Within coastal baseline National waters	Within coastal baseline National waters	Outside coastal baseline National/international waters
Examples of major producers	China Chile Norway	Chile Norway Mediterranean	USA (Hawaii) Spain (Canaries)

Figure 2.2: Differences between farming locations (Holmer, 2010).

The table in figure 2.2 mainly presents the environmental differences, where it is clear that the weather conditions and depth are getting rougher and deeper the further out from shore you get. This can be seen from the rows above for *physical setting* and *exposure*. The increased intensity makes the locations less accessible, and creates several challenges that will be further elaborated in section 2.2.2, page 12.

2.2.1 Categorization and characteristic

As mentioned in the above section, there are no specific formal definition on *exposed*, but there are several categorizing options. One way is to use the terms mentioned in figure 2.2, page 10 based on physical settings, degree of exposure, or legal definitions. Another solution is to use the site classification mentioned in the Norwegian standard (NS9415:2009) (NS9415, 2009; Sandberg et al., 2012), annex A, where “E” and “e” classifies “extreme exposure”. Class E indicates significant wave heights (Hs) above 3 m, and class e indicates midcurrents above 1.5 m/s (NS9415, 2009; Utne et al., 2015). According to Bjelland et al. (2015), the most exposed locations currently in use in Norway have significant wave height of approximately 2.5 m, and current speed up to 1.0 m/s.

The current most frequent used explanation is that these areas are more exposed to high waves, strong currents, and strong winds compared to other sites (Sandberg et al., 2012). They are characterized by geographical remoteness from onshore infrastructure, demanding sea states, and more extreme and unpredictable weather conditions. This includes higher significant wave heights, irregular wind, and strong sea currents (Bjelland et al., 2015; Holen et al., 2012; Sund, 2016). These factors will make it more challenging to perform daily operations that fish farms requires, without increasing the risk of damage to the cage or the operating personnel (Thorvaldsen et al., 2013b; Sund, 2016). Operations in exposed areas will therefore require more detailed planning for risk mitigation purposes, and to make sure that periods with sufficient weather can be utilized as good as possible (Thorvaldsen et al., 2013c).

2.2.2 Challenges

The challenges related to the sheltered sites, are most likely to be amplified when moving into more exposed areas, also seen in fig 2.2, page 10. This poses unique challenges to operations, structures and equipment (Bjelland et al., 2015). Operations will as mentioned be harder to carry out safely, and structures and equipment needs to be more robust (Utne et al., 2015). Lack of regular operations such as feeding and feed distribution will be critical over time. More about the operational challenges in section 2.5, page 17.

Lack of knowledge also applies to environmental impacts. Moving into more exposed areas could attract larger and more abundant predators, such as sharks and killer whales. These can attack the fish farms, and cause a massive escape of farmed fish into the wild, which will be a major problem (Holmer, 2010). Another challenge is the lack of research on how the fish actually reacts to the exposed area when it comes to the environmental conditions above and under the surface (Bjelland et al., 2015).

Sandberg et al. (2012) points out in their report, several safety challenges that will occur at more exposed sites. Challenges such as:

- Fish health, and prevention of fish escape
- Things take time in bad weather
- Fragile logistics because of bad weather, and limited weather windows
- Operations are highly dependent on personnel with experience
- All important criteria must be common
- Economical perspective on development of new equipment
- Unfavourable working positioning for the workers

The survey conducted by Sandberg et al. (2012) further shows that the challenges mentioned above are important measures in terms of good health, safety and environment in aquaculture at exposed locations. The list below shows some of the precautions they came up with:

- Important to provide sufficient amount of time, and count for greater slack and time buffers.
- Reducing the night work, and single working tasks under difficult conditions to avoid chances of accidents. In difficult circumstances, precautionary measures need to be taken into account on top of the regular risk assessments.
- Sufficient distribution of working hours to take care of the personnel's health. In addition to provide necessary practical and safety expertise and experience.

Considerable difficulties related to keeping a reliable production have been reported by fish farmers who have already started utilizing some of the more exposed areas. The few productive exposed sites today have shown acceptable growth and fish welfare, but the rough weather have also caused increased mortality because of stress (Bjelland et al., 2015; Utne et al., 2015).

Relocation towards more exposed areas imply the need for more automation, more autonomous systems, and more integrated operations (IO) to handle several of the challenges. It also requires reduction of manual workload, and more efficient IMR operations. Different types of surface vessels that can handle the different sea states will also be needed (Utne et al., 2015).

2.3 Divers

Divers need to have the diving licence to be allowed to do professional diving within the aquaculture. This requires a lot of specific training, and has to comply with regulations given by the authority (Lovdata, nd). Advantages by using a diver is the physical interaction that allows the diver to take actions right away. The major disadvantage is the high level of risk, because the diver has limited physical protection under water.

The law also sets specific requirements for the equipment, since diving operations could be very dangerous, especially in more exposed areas characterized by unpredictable weather conditions. Equipment like an on-site hyperbaric chamber, and diver-to-surface communication system are both required and important. Further elaboration of the necessary equipment will not be presented in this thesis, but the advancement of all diving methods are continuously pushed by the urge to further expand the aquaculture into more exposed areas (Solem, 2017).

2.3.1 Diving operations

Several aquaculture operations under water require divers, which are commonly used for detailed work that the ROV or other equipment can not yet handle. Operations such as repair of nets (see figure 2.3) and mounting of ropes are mostly implemented by divers today. Some companies also hires divers for inspection purposes, but that depends on the situation, since divers have limited diving time. Normal procedure is that fish farm companies hire a diving company, who has specialized on these tasks to take care of the operations (Fenstad et al., 2009).

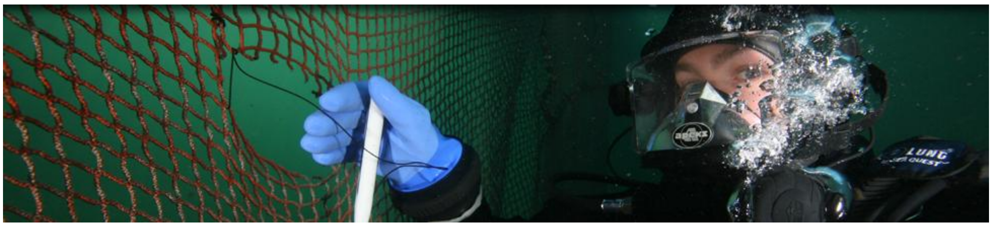

Figure 2.3: Repair of holes by a diver (internet).

There are several challenges connected to diving operations, such as water depth and environmental factors. Electrical exposure is also a risk moment when dealing with equipment under water (Sandberg et al., 2012). The extreme weather that are most likely to occur at the exposed areas will create extreme movements in the upper layer of the sea, because of strong currents. This makes it hard for the diver to stay at one specific place during operation, which makes "keeping still" a very energy consuming task. Very cold weather will also decrease the diving time, as dealing with the cold temperatures requires more energy from the diver (NavalSea, 2008).

More about operational challenges in section 2.5, page 17.

2.4 Remotely Operated Vehicles (ROVs)

Remotely Operated Vehicle, further referred to as ROV, is a simple box shaped vehicle used for different underwater operations. They can be controlled from the surface since they are unmanned (Sønstabø, 2016). The design has a floating element on top, and an aluminum frame. Typical qualities are that they can observe surroundings through cameras, and position itself via a cable, further referred to as the umbilical. The umbilical provides the ROV with unlimited power supply, and allows for regular data and general signal transmission (Rundtop, 2017; Sperre, 2016). ROVs are very often custom made, and will therefore vary in weight, size and price, due to the customers given specifications. The ROVs and the additional equipment are in general very expensive (Rundtop, 2017). Figure 2.4 shows a typical ROV used for several IMR operations in the aquaculture today.

Figure 2.4: A typical ROV used for aquculture operations (Sperre, 2016).

ROVs can according to NORSOK (2003) and IMCA (2013) be classified into five categories:

1. Pure observation (class I)
2. Observation with payload (class II)
3. Work class vehicles (class III)
4. Seabed-working vehicles (class IV) - Towed or bottom-crawling vehicles
5. Prototypes or development vehicles (class V)

The classes will not be described in detail here, but the main difference lies in what operations they can perform, given by size and additional equipment. Most of the ROVs are free flying, but some are also bottom founded (for instance class IV). The aquaculture uses the free flying ones, and mainly class II or III (NORSOK, 2003). ROVs are commonly used, and have become a well-developed indispensable tool to the fish farm industry. The fact that they can be controlled from above surface is a huge advantage, indicating no man in the water, which sometimes allows the ROV to spare the diver from the most dangerous situations (Sund, 2016).

Standard equipment on a ROV is a camera providing HD-quality, lights, and sometimes an arm, in addition to other vital equipment such as thrusters, floating element, etc. Working class ROVs usually have this arm, which is a hydraulic arm for operational purposes (Ludvigsen, 2015; Schjølberg and Utne, 2015). Customers can also choose whether they want to have a positioning system, and a navigation system. The navigation system gives a better overview, because it can provide both position and speed in all the six degrees of freedom. ROVs are to a certain extent autonomous, and they can be equipped with a wave point tracker, or a line tracker, allowing the ROV to for instance follow a pipeline in the same way as an Autonomous Underwater Vehicle (AUV) (Rundtop, 2017). The possibilities of carrying additional payload is useful for several purposes, such as being able to carry cleaning tools for net cleaning (Sønstabø, 2016).

2.4.1 ROV operations

Currently, industrial ROVs have no automatic control functions, and needs to be directly and manually controlled by an operator (Schjølberg and Utne, 2015; Utne et al., 2015). The operations are therefore highly dependent on the experience and qualifications of the operator. This will be important to ensure operations with high efficiency and quality (Bjelland et al., 2015; Schjølberg and Utne, 2015).

Every ROV operation needs at least two people. One to handle the umbilical, and one to steer the ROV. Common for most service companies are to use only one ROV at the time during operation, and normal procedure is to videotape the whole operation as documentation. The video requires no specific edition after operation, and creates an advantage of being live streamed. Live streaming allows the operator to investigate more if something suspicious occurs (Rundtop, 2017).

General observations, inspections of moorings and net, and net cleaning are the most common ROV operations, more about this in section 2.7, page 28.

The main advantage has already been mentioned: The fact that you do not need any personnel under water. The umbilical creates an advantage of "unlimited" power supply, allowing the operators to use the ROV for as long as they want to. The umbilical could also be a disadvantage because of drag and motions that appears because of more extreme weather conditions (Ludvigsen, 2015). Another disadvantage for the ROVs are that they can not be used for very large and detailed operations. The technology has not developed enough for that, so current situation is that divers still must do the very detailed operations such as net repair.

Main challenge for the ROV operations is the launch and recovery, which is very vulnerable to weather changes. Other common challenges are connected to navigation, power supply, and control. Navigation problems can occur because of acoustic, optic, virtual reality, or magnetism disturbances. It has already been mentioned that everything necessary to control the ROV are transferred through the umbilical. The length of the umbilical and diameter, is therefore important in terms of required power and other necessary signals that need to go through (Ludvigsen, 2015). More about operational challenges in section 2.5, page 17.

2.5 Operational challenges

The aquaculture industry has to deal with several challenges related to both fish welfare and operational conditions.

2.5.1 Environmental impacts

Moving towards more exposed areas are believed to have several advantages for production, and to decrease the environmental impacts from the aquaculture (Bjelland et al., 2015). Environmental impacts are very often caused by bad operational procedures, or procedures where something goes wrong. Knowledge about environmental impacts from exposed areas are currently limited, because of relatively few operational full-scale offshore farms (Holmer, 2010).

Contamination and waste dispersal

Fish farming always leaves waste behind in the ocean, which causes negative consequences for the wild species, and the benthic environment that includes the coastal flora and fauna. It could be from various chemicals, such as antifoulants (Holmer, 2010). Relocation also indicates longer distance from shore, which will increase the energy use for transportation of equipment, materials, feed and cultured fish that will increase the carbon footprint (Holmer, 2010).

Current situation is that the coastal line is getting overcrowded, there is lack of space. According to (Holen et al., 2012), relocation to exposed areas will lead to less conflicts about the use of coastal waters. This will give less environmental impact from the aquaculture industry in the fjords (Holen et al., 2012; Jensen et al., 2012).

On the other hand, exposed areas are believed to feature better water quality, because of low nutrient concentrations, less influence from coastal activities and terrestrial run-off, which will make it easier to keep the culture conditions stable over time. Low nutrient concentration will reduce the risk of phytoplankton blossoms, including other toxic species (Holmer, 2010; Sandberg et al., 2012). Exposed areas are also assumed to have more stable water flow conditions compared to he sheltered sites. This will make farm waste more diluted, and give greater dispersal that will decrease the environmental impacts (Holen et al., 2012; Jensen et al., 2012; Utne et al., 2015). Relocation will therefore strengthen the industry and give a higher value creation, because of better growing conditions for the fish that most likely will give higher fish density (Holen et al., 2012; Holmer, 2010).

Several people working in exposed areas says it is for the better for the fish and environment, though it is tougher and more dangerous for people to work out there (Sandberg et al., 2012).

Fish escape

The present level of fish escape is a problem for the Norwegian aquaculture industry, and could with time cause a problem for the future sustainability of the industry (Jensen et al., 2012; Thorvaldsen et al., 2013a). It is rated as a worst realistic scenario, similar to fish death, as there is nothing positive about it. What is negative is that the fish cannot be sold on a demanding market, it can only spread diseases or menace other wild important species (Størkersen, 2011).

Unpredictable weather conditions increase this risk, which can cause severe consequences to corresponding wild fish stocks (Bjelland et al., 2015), and also negative economical effects. Fish escape are often caused by technical and/or operational failures (Jensen et al., 2012), but human errors and factors are also mentioned as a main challenge to prevent escaping (Thorvaldsen et al., 2013a). Human errors have been the main reason during the last decade (Holmen et al., 2017a).

Escaped Atlantic salmon from fish farms are able to live very well in the wild (Naylor et al., 2005). The most typical consequences for the wild stock when farmed fish escape are transfer of diseases and pathogens, genetic impact because of interbreeding, and competition for food (Holmer, 2010; Jensen et al., 2012).

Moving out from the sheltered fjords into bigger areas such as the exposed ones indicates larger distance between the farmed fish and the wild fish. That will reduce the negative ecological consequences of transfer of sea lice and other diseases (Bjelland et al., 2015). Sea lice can cause the industry a lot, and are the most pathogenic parasite in salmon farming. Spreading will cause critical consequences for the wild fish if escape occurs (Costello, 2009).

Larger distance will also reduce the genetic impact of interbreeding between farmed and wild fish. Negative effects of interbreeding are the creation of hybrids that will influence the genetic variety. Negative outcomes are loss of local adaption and reduced reproductive success (Bourret et al., 2011; Naylor et al., 2005). Fish escape also harms the industry's reputation, because of the environmental credentials and waste products (Jensen et al., 2012; Thorvaldsen et al., 2013a), which will propagate into substantial financial and legal consequences (Thorvaldsen et al., 2013a).

2.5.2 Environmental challenges

The demand for fish is increasing, but right now the Norwegian aquaculture is producing on the limit of what is profitable (Bjelland, 2017). The major challenge is the environment, which makes the industry one of the most dangerous occupations to work in (Thorvaldsen et al., 2013a; Utne et al., 2015). High waves are most challenging for operations over the surface, such as crane handling etc. Operations under water are mainly affected by strong currents (Sandberg et al., 2012). Figure 2.5 shows how fish farms can look in extreme weather (Sund, 2016).

Figure 2.5: Fish farms in extreme weather (Sund, 2016).

Despite the challenges and consequences of moving into more exposed areas, there are still an increased interest in doing so. Most of the involved people agree that even though risk reduction of fish escape is a major priority, the safety of the personnel comes first when testing out new locations (Sandberg et al., 2012).

Unpredictable weather changes

Aquaculture operations are typically very susceptible to weather changes, which creates challenges when it comes to safety for personnel and fish (Holmen et al., 2017b). Harsh environments are often associated with unpredictable weather, including strong currents, and high waves. This indicates that the winter season is the most challenging time of the year. Darkness and cold temperatures also influences the working conditions (Thorvaldsen et al., 2013a). All these factors indicate higher risk of accidents for the personnel. Personnel accidents such as crushing, falling, and drowning are common when the waves get too high. Rough weather will also increase the amount of wear and tear on moorings, ropes and nets, where holes in the net can lead to fish escape. For service workers it can delay operations for days that will give critical consequences for the fish over time (Holen et al., 2012). If a delay happens, companies have agreed that they need to take the time necessary to finish and do the task properly (Størkersen, 2011).

Day-to-day operations such as feeding and net cage maintenance will most likely be less regular because of the weather, which can lead to economical and environmental catastrophes as starvation or fish escape (Bjelland et al., 2015; Størkersen, 2011). Unforeseen weather conditions add time pressure to the workers during the daily operations, which makes room for them to do "idiot mistakes", because of the limited time (Størkersen, 2011).

Extreme weather causes huge forces, which can damage the equipment and cause breaks. Humidity in instruments, data signal disturbance, breaking of power cables, etc, are also problems that can occur. Moving into more exposed areas will therefore require further development of robust equipment such as robust structures, and cages (Thorvaldsen et al., 2013c).

Limited weather window

The biggest challenge is the harsh wave environments (Sandøy, 2016), which result in limited weather windows for the exposed areas that can influence the quality of the operation by affecting the efficiency. The unpredictable weather requires ROV operators with greater skills and the ability to make quick and correct actions when needed, to minimize the chances of equipment failure, fish escape or other occupational accidents. A skilled operator will also increase the chances of doing a safe and efficient operation. Relocation into more exposed areas will increase the demand for such operators (Bjelland et al., 2015; Utne et al., 2015).

Strong currents and high waves

Operations often have to be called off when the weather gets too extreme. This is due to safety of the workers, but also to minimize the risk of damaging the equipment (Rundtop, 2017). There are no formal stop criteria, but the operators usually make the call themselves. The ability to make quick and correct decisions are therefore important due to the rapid change of situations (Holmen et al., 2017a).

Strong currents could be a challenge if the thrusters are not strong enough and make the maneuvering of the ROV difficult, in addition to keep the ROV still in the water. High waves cause a bigger challenge than the currents, because of the launch and recovery (Rundtop, 2017).

Effect of water depth and darkness

Effect of water depth is most severe for the diver, because pressure increases due to depth. "A diver will normally experience 10 times the pressure at sea level when making a dive. This pressure will cause lung gases to dissolve into the blood, which will affect how long the diver can remain under water" (Solem, 2017). Too long exposure might result in decompression sickness when reaching the surface. It does not matter how trained the diver is, water depth will always be a limitation, and the divers diving time depends on the depth of the operation (HSW, 2017).

Currently, fish farms are located from the surface and down to a certain depth, which indicates that for now, water depth is not a major challenge. Darkness on the other hand is challenging, and especially during the winter season when it is limited time with daylight. To deal with the darkness divers use underwater flash lights, while ROVs have lights as part of the standard equipment. The challenge with using lights are that fish sometimes get attracted to the light, making the operation more challenging to proceed (Rundtop, 2017).

2.5.3 Need for automation

As previous section indicates, section 2.5.2 page 19, there are several environmental challenges that screams for the need of more automation.

Environmental challenges will create limited operational weather windows, which will make it difficult to carry out operations in a safe manner for the operating personnel. It is therefore desirable to find solutions where less people have to be present to carry out operations that today are manually operated (Bjelland, 2017; Utne et al., 2015). More frequent use of autonomous and remote control options such as ROVs, vessel control and cage-integrated intervention tools will help enlarging the weather window without putting any personnel at risk. This will make it easier to plan for required operations as fish handling and lice treatments (Bjelland et al., 2015).

In addition to what has already been mentioned, severe weather conditions will also cause negative impacts on power supply, which can lead to more frequent failures. This induces challenges as stable power supply, which is a prerequisite for autonomous systems as ROVs. Sea-keeping ability of support vessels will also be affected as most operations requires the surface vessel to be stable and at place (Bjelland et al., 2015).

The need for automation is there, but willingness to try out new available technology can sometimes be a challenge. Sandberg et al. (2012) mentions in their report that there are more available technology that the aquaculture industry chooses not to buy or use. Equipment that can improve the safety of the workers, such as LiftUP (system for removal of dead fish), man-over-board-alarm, new boats, and cranes mounted on fleets. Their report state that several companies instead choose to create their own solutions, because "they are good enough for the work to be done" (Sandberg et al., 2012).

2.6 Regulations

Regulations are important, and several chief executive officers (CEO), can confirm that regulations have done something to the industry. For instance are several companies more willing to invest in better and safer solutions after the new technological standard (NYTEK) was implemented (Thorvaldsen et al., 2013b).

The first section here is quite complementary, to give an overview of what is actually required from the authorities due to different aspects of operations. The next two sections, section 2.6.2 and section 2.6.3 are shorter. The reason for that is because regulations only play a minor part for this thesis. They will not be discussed or questioned in detail.

2.6.1 Aquaculture regulations

Customers usually set the requirements concerning the operation, but most of them are also regulated by laws given by different authorities (Fenstad et al., 2009). Most service companies need to adapt to the regulations given by NYTEK and NS9415 when it comes to competence, system requirements, and operational procedures (AQS, nd).

The Norwegian technological standard NS9415 sets requirements regarding the fish farms and specific the net pens, floating collar, rafts and mooring systems. The standard is also relevant when looking into site surveys and general requirements for inspections and operations . What this standard does not cover is how to prevent fish escape (NS9415, 2009). NYTEK and NS9415 are highly connected, more about NYTEK under section 2.6.3.

Sea lice and fish escape are two major challenges within fish farming, and workers do everything they can to minimize the appearance of these events. This can sometimes put safety for the workers in the shadow (Hage and Torsvik, 2016; Holmen et al., 2017a). To make sure that safety is prioritized, the aquaculture industry must comply with several regulations and requirements affiliated with safety. These are decreed by law, and set by several authorities (Bjelland et al., 2015; Størkersen, 2011), which means that the different authorities have the practical supervisory responsibility for security requirements that affect different work procedures (Hage and Torsvik, 2016).

The Directorate of Fisheries makes technical requirements for the venues and facilities, while the Norwegian Maritime Directorate sets requirements to design of boats, safety, competence of the captain, etc. The Working Environment Act is the primary authority that sets laws and regulations to ensure the workers' health, safety and working environment (Hage and Torsvik, 2016). Among other things, this regulation takes up limits on working time and when it can be conducted. These are important to ensure that workers have working hours that do not cause unnecessary health and social loads to the worker and their immediate family (Fellesforbundet, nd).

Ordinary working hours are normally 9 hours in 24 hours, and 40 hours in 7 days. For 24-hour continuous and full-time work, weekly working hours are limited to 36 and 38 hours in 7 days, respectively. These regulations are sometimes difficult to follow, because certain aquaculture operations require work beyond these limits (Fellesforbundet, nd).

Other relevant regulations to health, safety and environment are those given by The Directorate for Civil Protection and Emergency Planning, and the Local Electricity Authority. The Labor Inspectorate does surveys and sampling to verify that health, safety, and environment (HSE) provisions are complied within the companies. Violation leads to imposition to rectify the conditions within a given deadline (Fellesforbundet, nd).

When different companies are working together, they must choose one company to lead the operation. This company is responsible for ensuring that safety measures are taken. This is relevant when the fish farmers hires diving or ROV-services. Safe operation while the divers are in the water is especially important. If the risk can not be eliminated, the operators are required to stop the operation. The same applies for ROV operations. If the operation puts the crew at risk, it has to stop right away. All companies are required to report all accidents and injuries affecting the company's employees (Fellesforbundet, nd).

All workers working on or at a facility are entitled to a safe working environment, wherever they are. Every company is required to make sure their equipment and facilities do not pose any risk of injury to life or health for the workers. In the aquaculture, annual expert control is important on especially lifting equipment due to high risk of corrosion and wear (Fellesforbundet, nd).

A challenge with all the regulations are that some may be partly contradictory. One example is removal of dead fish that is required to be done daily. This is a very weather dependent task, which makes it a risky operation that challenges the HSE requirements for the workers (Hage and Torsvik, 2016). The authorities also require the companies to report all operations they do, but most companies only report abnormal situations and events (Fenstad et al., 2009).

Regulations have decreased the frequency of unwanted accidents in recent years, and made the workers able to focus on safety to both humans and fish. Coordinated regulations and collective responsibility are keys to keep this trend in the aquaculture (Hage and Torsvik, 2016). Companies are also required to document all operations, as a quality check and for learning purposes if a challenge had to be handled.

2.6.2 Regulations related to divers

Everyone connected to any diving operations are obliged to follow the regulations given for diving. Some are stated in the employment protection act (EPA)/working environment act (WEA). Violation of regulations can lead to police reporting (Fellesforbundet, nd). The main responsibility lies with the diving company, but during operation the client should also ensure that the requirements listed below are being followed (Fellesforbundet, nd):

- Should be at least three divers present: Work diver, spare diver and diving assistant.
- Everyone involved in the operation should have adequate qualifications, training and certificates according to the regulations.
- Procedures and routines for safe diving should be included in the diving company's internal control system.
- Documentation of all performed diving operations.
- Every operation should have a dive manager.

Chapter 26 in the diving regulation provides regulations regarding diving qualifications, documented safety training, responsibility areas for the various titles such as *diver*, *diving master* and etc. In addition to mentioning some dangerous activities during diving (Lovdata, nd).

Another important regulation is the Norwegian diving- and treatment tables. These tables have been written by Risberg et al. (2017), and provides "tables and guidelines for surface oriented diving on air and nitrox" and also "tables and guidelines for treatment of decompression illness". It is available online from *www.dykketabeller.no*. The book starts by presenting an emergency action plan that stepwise shows what to do in a diving accident. The plan can be seen from the figure 2.6 below (Risberg et al., 2017).

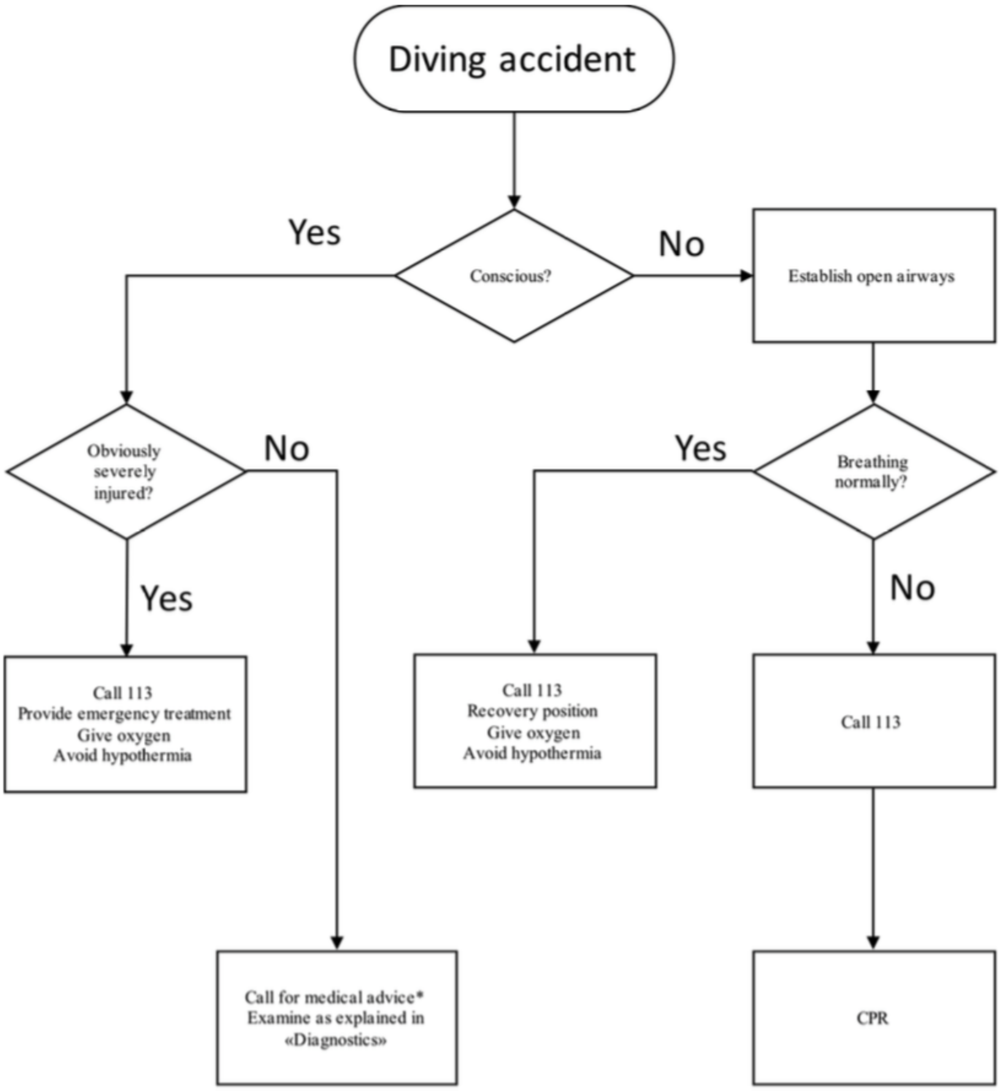

Figure 2.6: Emergency action plan for diving accident (Risberg et al., 2017)

NORSOK (2014) is written for the offshore industry, and states several relevant regulations related to diving. Topics that are mentioned are requirements concerning administration, health and environment, personnel, technical, operational procedure, and emergency preparedness.

2.6.3 Regulations related to ROVs

Aquaculture operations do involve certain risks for the facilities, fish, and the people operating. One regulation called *Akvakulturforskriften* (FOR 2008-06-17 nr 822) gives directions about adequate inspection, fish escape, and dead fish removal. (Akvakulturdriftforskriften, 2008).

One regulation highly relevant for ROVs are the NORSOK standard U-102, which has the title *Remotely Operated Vehicle (ROV) services*. The standard has been written to establish one single common standard for ROV operations offshore, and provides basic requirements for personnel, equipment and systems for ROV operations related to the petroleum industry. Several of these requirements also applies for the aquaculture industry. Some of the relevant topics are: ROV classification, documentation, reporting, crew requirements, and etc. (NORSOK, 2003).

IMCA is a guideline promoting improvements on how to handle ROVs due to better quality, health, safety, environmental and technical standards by publishing diverse information notes. When it comes to operational requirements, IMCA includes sea state, load path and deck loading, and regulations and classification (IMCA, 2013).

NYTEK is very relevant for use of ROVs, because it states different requirements according to the procedure, the operating company, and documentation procedures that the company needs to account for when doing inspections. According to NYTEK, every mooring inspection needs to be documented, and several of the requirements stated in NYTEK refers to NS9415:2009 (Nytek, 2015).

2.7 Typical inspection, maintenance and repair (IMR) operations in aquaculture

Inspection, Maintenance and Repair can be shortened by IMR. Currently these operations require support from offshore vessels, divers and ROVs if they are under water (Schjølberg and Utne, 2015). As indicated before, normal procedure is that the fish farm companies hires service companies to do these kinds of operations (Fenstad et al., 2009). Some fish farm companies prefer to use divers for all types of operations, while others tries to use ROVs as much as possible for safety reasons. Usually they are free to decide whether they want to use a diver or a ROV. A recent trend is that several service companies have started to divide the workers into specialized groups for different operations (Sandberg et al., 2012).

It is common to distinguish between operations done from the inside and outside of the fish cages. ROV operations are usually done from the inside of the cage, because of all the mooring lines on the outside. Mooring inspection is the only operation done from the outside (Rundtop, 2017). Most IMR operations can be implemented by both divers and ROV. The main difference lay in who is more suitable to do what and when, and to what extend the task need to be operated manually.

Currently, there are several important and challenging IMR operations, such as delousing. Delousing is very risky, because it requires assistance from huge cranes, which sometimes overrides the capacity of the service vessel and makes it unstable (Sund, 2016). The operation requires skilled people to decrease the risk of personnel and fish escape (Holmen et al., 2017a). Examples of other IMR operations under water are: Inspection operations on nets, moorings or cables, net cleaning and washing, removal of dead fish (usually done manually by a service worker), mounting of ropes, repair of holes (done by a diver), and mooring installation.

This master thesis will mainly focus on three operations: Net inspection, mooring inspection, and net cleaning. According to the service companies, these are of the most frequent operations. To avoid too much repetition, and since one of the research objectives are to "expand and further develop knowledge about current diving and ROV operations in aquaculture, focusing on when, why, how, and challenges" (see section 1.3.1, page 4, the next subsections will just briefly describe the three selected operations. Further elaboration is in the result chapter, see chapter 4, section 4.5, page 66.

2.7.1 Net and mooring inspection

Inspections are currently the most frequent aquaculture operation in use, and they need to be done frequently. How frequent depends on the need, and each fish farm company are responsible to make sure it happens frequent enough for their facility to maintain a safe operational environment for the personnel, and a good growing environment for the fish. The purpose of these inspection are to inspect and check that everything is ok with the net and the moorings respectively, in relation to different deviations such as holes in the net, or wear and tear on mooring chains. Inspections are highly necessary to discover damages (Sønstabø, 2016).

Both divers and ROV can be used for inspection purposes, where ROV is the most efficient choice. Standard procedure is to launch the ROV and make it follow the net, filming everything for documentation in case of special findings.

2.7.2 Net cleaning

Net cleaning can be performed by both divers and ROVs, and it is a highly important part of the maintenance routines. The cleaning process is important to reduce the amounts of marine fouling and algae growth on the fish net (Utne et al., 2015). Fouling and algae growth can prevent the oxygen supply and increase bacterial loads, causing diseases, bad environment and stress for the fish (Akvagroup, 2015a,b).

Cleaning procedures performed by divers are very risky. Several divers categorizes this as an easy task, but the major challenge is time. The operation is time-consuming, which will affect the divers condition over time (Fenstad et al., 2009).

Instead of divers, net cleaning is often performed by a ROV using specialized high pressure cleaning rigs, and cranes that are operated by service workers located on the service vessel (Bjelland et al., 2015; Utne et al., 2015). A ROV is very practical, because it can carry the cleaning tool as payload. It can also be used for general observation, and inspection at the same time, which is very efficient since inspection is necessary after the cleaning operation (Sønstabø, 2016).

As will be mentioned later in the result chapter, section 4.5.3 page 74, there are two additional tools mentioned for net cleaning, one remotely operated net cleaner (RONC), and one flying net cleaner (FNC). Here are a brief overview of them:

Terminator

Terminator is a multi pump innovation cleaning rig, which can be attached to the front of the ROV, see figure 2.7. It washes the net by using water with high pressure (MPI, 2017).

Figure 2.7: Terminator (MPI, 2017)

Remote Operated Net Cleaner (RONC)

RONC is a quite new purpose-made vehicle based on the ROV principle. It is a huge rig with thusters, and an advanced ballast system. Is it very efficient and can do the cleaning within an hour (Rundtop, 2017). See figure 2.8 and figure 2.9 for pictures of the backside and frontside of the RONC, respectively.

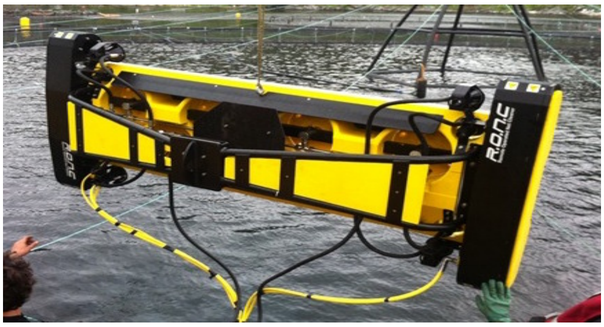

Figure 2.8: RONC backside (MPI, 2017).

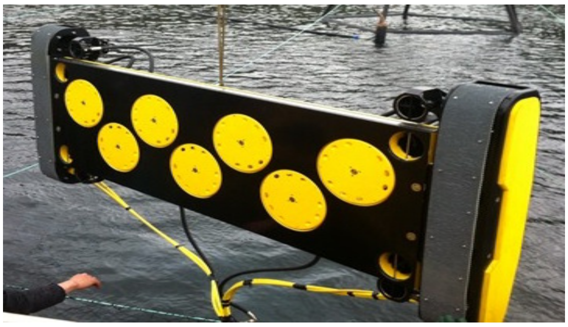

Figure 2.9: RONC frontside (MPI, 2017).

Flying Net Cleaner 8 (FNC 8)

Figure 2.10 shows a FNC 8, which is not a ROV, but a remotely operated net cleaner that can clean an area of 5.000 m^3/hours. It requires a minimum of maintenance and is an open construction (Sperre, 2016).

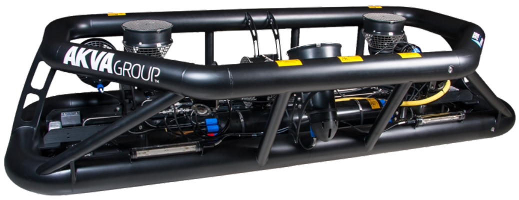

Figure 2.10: Flying Net Cleaner 8 (Sperre, 2016)

2.8 Relevant research

Most of the definite goals for the future are concerning sea lice. The sea lice is a big problem, and current methods are not good enough. To check around 20 fish out of over 20,000 is not representative. In addition is product development very important. One challenge is that the industry sometimes could be a little impatient, which causes too fast production development. It is important to keep in mind that offshore solutions need modifications if they are supposed to be used within the aquaculture instead (Bjelland, 2017).

Currently, there has been a lot of development, but little that has happened. Head of research for SFI Exposed Bjelland (2017) believes that the next five years will consist of a lot of testing. Especially when it comes to new fish farm facility concepts, because they are most likely to increase in size for economical reasons in the future (Holmer, 2010).

2.8.1 Fish farm structures

Fish farm structures have been worked on for years, and several concepts exist today. The dominant concept for farming of Atlantic salmon i Norway is the flexible floating net-cage systems. The Norwegian standard NS9415 specifies the technical design requirements (Bjelland et al., 2015), related to the design of feed barges, floaters, net cages and mooring systems that are necessary to cope with environmental forces such as wind, waves and currents. It also specifies how to handle and use different equipment (Jensen et al., 2012). These requirements took effect in 2004, and have been important to decrease the number of escaped Atlantic salmon (Jensen et al., 2012).

The newest development within fish farm structures are SalMars new *Ocean Farm 1.* It is the world's first offshore fish farm, and it is said to be the start up of a new era in fish farming (SalMar, 2017).

2.8.2 Safety

When it comes to use of ROVs there are some lack of research and knowledge. There are very few, none found during this work that are linked directly to ROV operations. One relevant work is done by Thorvaldsen et al. (2013a), who in 2015 wrote an article about how to prevent fish escape that mentions several important factors around operating in harsh weather characterized by high waves and strong currents. The article presents how some companies conduct on-the-job training, how they co-operate and communicate with other contractors, and how important it is that all workers have a common understanding of what to do to maintain a safe operation. The conclusion of the article is that "safety for both fish and people can be improved by simplifying operations and improving equipment".

Another relevant work is done by (Fenstad et al., 2009), who in 2009 did a project where they used qualitative surveys to check the routines around safety when working at and around fish farms. Several workers said they just had to use their common sense, but that the industry is on its way to become more specialized (specific companies for different tasks), centralized (larger companies) and fragmented (several involved companies). This indicates new challenges connected to education and cooperation, which presumably will increase the safety of the workers over time. Workers pin point the weather as the most challenging factor, and that they see the value in increased automation.

2.8.3 Increased use of ROVs and more autonomous solutions

Safety and economical benefits are important factors when talking about expansion. There are several research projects working on how to improve and develop better solutions to cope with the challenges that the exposed sites bring and one trend is that it will be more automation, including more use of ROVs and Autonomous Underwater Vehicles (AUVs).

There has been an attempt to use AUVs, which have been working to some extent. The problem is the fact that AUVs are pre-programmed, which means that when it is launched into the water it kind of drives itself. The "only" thing the operator can do is to cancel out the operation if an emergency occurs. The challenge is the unforeseen movements of the net, how to program the AUV so that it avoids the net (Bjelland, 2017). AUVs are also very expensive, and they require a lot of processing after the operation (Rundtop, 2017).

Schjølberg and Utne (2015) presents an on-going research project where focus is on how technology development can enable more autonomy in ROV operations. The project presents that increased autonomy will allow the ROV operators to shift from manual to automatic control for certain tasks, and that it will be a stepping-stone to increase operational efficiency, and cost reduction. Automation will also reduce the workload of the operator, and minimize the appearance of human errors. Their temporary conclusion is that there is still a huge gap before autonomy will be noticeably integrated in ROV operations, as there are several challenges that needs to be solved, challenges such as localization, path planning, design of templates, and risk management during autonomous operations. They believe it might happen in the future as there is a large effort on the investigation side.

Another current research project is *SustainFarmEx*. This project involves several aquaculture companies such as SINTEF and NTNU (Holen et al., 2012). The purpose of *SustainFarmEx* is to investigate and gain knowledge about how fish farming operations can be implemented in a safe, reliable and profitable manner, and how they can be suited for the exposed areas. The project is funded by the Research Council of Norway and industrial partners, and they have already managed to do extensive numerical simulations, model trials and field studies throughout the different sub-projects.

Artifex is also a project run by SINTEF. The purpose of the project is to develop new robot technology that enables daily and periodic IMR operations to be performed from a land based control center. This will provide a reduced risk for those who in the future will operate on more exposed sites (SINTEF, 2016)

Reducing risk in aquaculture - Improving operational efficiency, safety and sustainability is another ongoing research project associated with SFI Exposed. This project is highly relevant for the master thesis, as the thesis is meant to make a contribution to the project. The project is organized by the Institute of Marine Technology at NTNU, and SINTEF Fisheries and Aquaculture. It started in 2016, and is supposed to be completed withing 2019. The objective is to improve the safety and efficiency of aquaculture operations, by looking into new and more autonomous solutions (Sund, 2016). The EXPOSED-center wants to use Norway's strong position and knowledge in maritime sectors to find better solutions that enable safe and sustainable seafood production in vulnerable coastal and marine areas (SINTEF, 2015).

On the 24th of July 2017, iLaks published an article telling about a new development for net cleaning, developed by a company named Aqua Robotics. The concept looks very much alike what already exist, but it is believed to be better, and that it will help keep the nets clean on a more regular basis (Berge, 2017). The concept will not be further described here, but the article proves that the industry is continuously working with new concepts that will improve what we already do.

Chapter 3

Methodology

This methodology chapter explains the implementation of the different methods in the master thesis, how they have been used and different limitations to be aware of. It also justifies the choice of methods, by mentioning some of their benefits and weaknesses.

The methodological approach in this master thesis includes literature review, observations through three field trips, and interviews and conversations with different stakeholders.

No personal information has been collected or stored through the work of the master's thesis. Involved individuals have therefore been treated anonymously and handled according to the principles given by the Norwegian Data Protection Official. To enhance the reliability and validity of the collected data material, all companies have given the permission to mention their company's name in section 3.4.2.

3.1 Method selection

There are two types of methods, quantitative and qualitative. Quantitative methods are characterized by numerical information based on several investigations. Collected data are easy to re-examine, due to high emphasis on precision. This method is usually required for documentation and obtaining of evidence (Samset, 2014). Quantitative methods have a wide area of application, and with the goal of creating an overall understanding of the subject (UiO, 2005).

Qualitative methods are characterized as comprehensive textual information, based on just a few investigations. The results are highly relevant to their situation, but hard to re-examine. These methods are necessary to describe context and further discuss the results (Samset, 2014). Qualitative methods are often very limited i range, and with the goal of providing in depth knowledge. They are useful when investigating areas where there is currently a lack of knowledge (UiO, 2005).

A qualitative approach through literature review, observation, conversations and interviews with stakeholders have been chosen in order to get as genuine an impression as possible of the current situation. These methods have been chosen with respect to the overall objective of the thesis. It has also been considered necessary to use qualitative methods, because the thesis are investigating an area where there is currently a lack of knowledge. Another argument for using qualitative methods is that compared to other studies, the scope of this is relatively narrow, even though it covers several of the relevant stakeholders in the Norwegian aquaculture.

Two terms that would be mentioned in some of the following sections are validity and reliability. Validity states to what extent the results from the study are prevailing. While reliability states to what extent the study can be re-examined (Dalen, 2008)

3.2 Literature review

A literature review was carried out in the project thesis and continued in the master thesis, to get an overview on current knowledge on the field. This has been important to form a solid theoretical basis. The literature was mainly found through the NTNU University Library Oria, and google scholar by using keywords as: *ROVs*, *automation in aquaculture*, *exposed aquaculture*, *ROV operations*, and *ROV challenges*. Several references have been found by reading the bibliography at the end of relevant articles. To maintain a critical approach to information references, and assure the quality of the information, several independent references on the same topics have been applied. Especially when using general web pages.

Blumberg et al. (2014) describes the literature review as an essential part of every research project, and it is important for several reasons: Establishing the context of the problem by reference to previous work, understanding the structure of the problem, present related theories and ideas, etc. His book presents different aspects on how to search for good enough sources, how to evaluate them, how to present them and how to process them.

The literature study was conducted after guidelines provided by Blumberg et al. (2014):

- Define the scope and what to achieve through the literature review
- Use different sources such as dictionaries, manuals, and textbooks to identify keywords, people, or events relevant to what one wants to figure out
- Use the keywords, people or events to search for indexes and bibliographies, to identify relevant secondary sources.
- Find out and read through the specific secondary sources.
- Evaluate the content for each source and its content.

A literature review should have a good reliability, by high degree of verifiability. A well arranged bibliography makes the re-trace easier for the reader, and others that are interested in reading the primary sources. To make sure the sources are good enough and to increase the validity of the literature review, all sources where criticized through the principle of *TONE*, which according to NTNUUB (2017) stands for :

- **T-Credibility:** An assessment of the author's knowledge and recognition. Evaluation of occupational qualifications due to education and position for the author, as well as affiliated institution.
- **O-Objectivity:** Discussion about whether the publication is consistent or in conflict with earlier research. The intention of the publication is also assessed.
- **N-Accuracy:** Assessment of the research method. Is the publication explained good enough, is it up to date, and could it be acknowledge by at least two other resources?

- **E-Suitability:** How suited the article is for the intended thesis. How relevant the publication is, and to what extent it can bring valuable inputs.

The purpose of the literature review has been to support the knowledge gained from the companies, and also to form a solid basis for both the theoretical background chapter and the methodology chapter.

3.3 Observation through fieldwork

Advantages with conducting direct observations are the ability to immediately cover actions that are in real time, and also to see the big picture of the operation. Disadvantages are that it is time-consuming, and highly dependent on others to have something relevant to observe. Reactivity is also a weakness, indicating that workers may proceed with the operation differently, because they are being observed (Bernard, 2006; Yin, 2014).

Observations are in general the best and most useful way of getting detailed information about operations in practice, and to provide additional information (Yin, 2014). Operations within the aquaculture industry is sometimes very unpredictable, because the operators needs to take actions due to the changes in situations that can happen because of weather changes etc. Observation allows the observer to easily understand how stressful this could be, and to ask questions about different decisions, if the situation allows it.

The observations for this case were made as non-participating observations where the observer observed service workers without even participating in any operations (Fangen, 2015). It was desirable to visit as many service companies as possible to get a visual insight into how a normal working day could be like, and how different operations are carried out. During the period of the master thesis, three field trips were carried out. One trip to a fish farm in the beginning of the semester, and two trips to two different service companies in May. Observations of a pipeline inspection, and a mooring inspection were done at the service companies respectively.

The field trip to the fish farm is not that relevant for the thesis, and observations from this is provided in the appendix, see appendix B on page B-1. The pipeline inspection is not that relevant either, since the thesis has chosen to focus on net inspection, mooring inspection and net cleaning. Some of the pipeline observations are still very relevant when looking into how a company with access to both divers and a ROV operate. This observation is also provided in the appendix. Observations from the mooring inspection is described in the result part.

3.4 Interview as method

Interviews and conversations are valuable methods of data collection, because it allows the interviewer to talk to experts that can either help directly or give valuable tips about who else to contact (Bernard, 2006).

Yin (2014) presents the strengths and weaknesses of the interview as a method. Presented strengths are that an interview is direct and case-specific. It allows the interviewer to ask self chosen questions highly related to the topic. Another strength is that interviews provide insight, as the interview object provides explanations as well as personal opinions and views, reflections and attitudes. Potential weaknesses are poorly articulated question, leading to bad and not very objective or accurate answers. Inaccuracy could also be because of the interviewers ability to perceive the problem. It is also a weakness if the interview object chose to give too short answers, or just give the answers he/she believes the interviewer wants to hear. The reflection process after the interviews is also very important, and also very vital for the outcome. It is important to do correct and detailed notes under the interview, so that the information can be used as accurate as possible.

The interviews proceeded in this thesis are according to (Bernard, 2006) referred to as *semistructured*, or *in-depth interviewing*, which is a scheduled activity. This type of interviews are helpful when dealing with people who have lack of time, and usually the answers end up with an open ending. Writing an interview guide is one way to make sure that all topics relevant to the thesis get covered.

3.4.1 Interview guide

An interview guide is a prepared list of questions and topics that the interviewer wants to get covered during the interviews. The topics are in a particular order, creating a red thread for the interview, making it more professional (Bernard, 2006).

All interviews and conversations were based on the same interview guide, covering the following topics:

- Today's aquaculture.
- Exposed areas.
- Normal working day.
- Divers.
- Diving operations.
- ROVs.
- ROV operations in general.
- ROV operations in practice.
- Critical ROV operations.
- Decisions / Responsibilities.
- General safety management for ROVs.
- Training and follow-up.
- Collaboration ith other work teams.
- Cost and needs.
- The future.

The interviews took about one to two hours, and all appointments were scheduled over phone or by email, and conducted over phone or by personal meeting. The interview guide can be seen from appendix C, page C-1, and a description about the assortment of the contributing companies and interview objects are in section 3.4.2, page 42 and 3.4.3, page 45 respectively.

3.4.2 Contributing companies

This sections provides an overview over which companies that have contributed with their knowledge. The three following tables, table 3.1, table 3.2 and table 3.3 provide lists over the different companies, including one research company, one fish farm company, three fish farm equipment producers, and seven service companies.

Table 3.1: List of other contacted research company and fish farm company.

RESEARCH INSTITUTE	
	Sintef Ocean AS is a research institute aiming to help Norway continue to be leading within various maritime areas such as fisheries and catching, marine resources, marine, environment, new ocean industries, oil and gas, breeding, and processing. They "conducts research and innovation related to ocean space for national and international industries" (Exposed, 2016).
FISH FARM COMPANY	
	Marine Harvest Norway AS was established in 1965, with headquarters located in Bergen. They are currently the largest aquaculture company in Norway, and covers the entire value chain related to farmed fish, from feed production and roe to processing and sale distribution. The company is listed on the Oslo Stock Exchange (OSE), and their intention is to produce nutritious, delicate seafood of high quality, mainly salmon and trout that they deliver worldwide (MarineHarvest, nd).

Table 3.2: List of contacted fish farm equipment producers.

FISH FARM EQUIPMENT PRODUCERS	
	Aqualine AS is a major international supplier producing various equipment like float collars, mooring systems and fish cages.
	Argus Remote Systems AS is an equipment producer mainly producing ROVs and ROV accessories. They also provide research development.
	Sperre AS is an equipment producer mainly producing ROVs and associated equipment. The company lies under the AKVAgroup umbrella, and delivers ROVs and related equipment to both the fish farming industry, and also the oil and gas industry.

Table 3.3: List of contacted service companies.

SERVICE COMPANIES	
	Abyss Subsea is a service company providing both diving and ROV based subsea operations within aquaculture and offshore industry. Focus areas are development of cost effective solutions for subsea inspection, maintenance and repair (AbyssSubsea, nd).
	AQS AS is a solid maritime contractor based in Flatanger council, just outside Namsos. They were established in 1991, and have extensive experience in aqua service. AQS AS provides all kinds of specialized service to aquaculture, such as net operations, washing, and IMR operations. They also provide a wide competence within mooring systems and handling of fish due to delousing and amoebic gill disease (AGD).
	Frøy Akvaservice AS is a local partner located at Sistranda. It is one of six companies under the Frøy group. Frøy Akvaservice AS provides general service an bilge well wessel services for the aquaculture industry. (Frøy, 2015).
	Lerow AS a service company offering advanced ROV operations. They provide inspection and cleaning of net cages and mooring. Lerow was established in 2006, and are one out of 15 companies within the Bremnes group. They are located at Kjerringvåg at Hitra in Sør-Trøndelag.
	Nærøysund Aquaservice AS is based in Rørvik. They offer several ROV operations, and have today three boats equipped for usage of ROVs. Nærøysund does not have any divers employed, but they collaborate with others when needed.
	Norsk Havservice is based at Uthaug, and their main customers are SalMar, MarineHarvest and Refsnes Salmon. They have both divers and ROV operators have the main responsibility for the areas Orkanger, Ølandet and Rørvik. They do not provide any ROV operations on fish cages yet, but provides several other diving and ROV services such as pipeline inspections.
	Vikahav AS is a service company with a wide range of competence and experience. They offer several ROV operations within aquaculture.

3.4.3 Selection of interview objects

Reliability says something about the extent to which the study can be re-tested. It distinguishes between internal and external reliability. Internal reliability is to what extent other people can use the data in the same way as the original researcher. External reliability says something about the degree different researchers will discover the same phenomenon and generate the same concepts in the current or similar situations (Dalen, 2008).

Obtaining confirmation from others is one way to increase reliability of collected data, and strengthen the work (Dalen, 2008). The intention was therefore to talk to people from all of the different companies involved in fish farming: Fish farmers, service workers and equipment producers.

Interview objects (informants) were selected based on one main criterion, namely, that they could contribute with relevant knowledge to the scope of work. The main focus has been on service companies, since these are the ones operating the ROVs. In addition, fish farmers and equipment producers have been contacted to cover a broader range of today's situation, and also to follow up some of the information gained from the service companies.

Interviews and questions have mainly been completed on the field trips, or by phone to reach more companies. Table 3.4 shows an overview of all who have been contacted in connection with the master thesis. Relevant information was gained from different sources that varied from company to company.

Table 3.4 shows all the different positions/titles of the involved informants, where PhD is doctoral education, CEO is Chief Executive Officer, CTO is Chief Technology Officer, and COO is Chief Operating Officer. Since the informants are to be kept anonymous, the category *others* will cover the positions where just one person was contacted. These could for instance be SHE (Safety, Health and Environment)- and personnel officers. Since there is only one fish farm company related to this thesis, fish farmers will be referred to as service workers to keep the anonymity.

Table 3.4: Overview over contacted stakeholders.

Position/Title	Number of people
Researcher, PhD	3
CEO, CTO, COO, general manager	9
Operational manager, technical manager	4
Dive manager, diver	5
ROV manager, ROV pilot, service worker	8
Others	3

Chapter 4

Results

This chapter presents the results, and provides an informative foundation to the overall objective of the master thesis. Focus area is ROV operations, which characterizes the content.

The results consist of answers that have been gathered during the field works, interviews and other conversations. The presentation of the results have been based on the structure from the interview guide, where each of the sections more or less considers all of the associated bullet-points seen in the interview guide, see appendix C page C-1.

The gathered information provides a unique understanding, and insight into what the different types of participating companies thinks about the idea of moving fish farms into more exposed areas. As already stated in the methodology chapter, chapter 3, sec 3.4.2 page 42, the service companies and fish farm equipment companies are better represented than the fish farm companies.

To satisfy the requirement of anonymity, all companies will be referred to by company type (service, farming, equipment producer) rather than company name. Also as mentioned when presenting table 3.4 page 46, fish farmers will be referred to as service workers, because it is only one contributing fish farm company in this case.

4.1 Normal working day

A normal working day includes several factors such as composition of working hours, documentation procedures, and use of supporting equipment.

4.1.1 Working hours

The diving industry is very hectic, depending on season and scope of work. They usually work 12-13 hours a day in two weeks before having time off. Divers take part in all operations when on board. Under normal circumstances, a normal working day will vary from 7:00 AM to 19:00 PM. Divers are used for several types of IMR operations on sea cages, such as net repair, washing of pontoons, and bolting. Inspection of bolts and mooring systems are usually conducted by ROVs. The working day of a diver is hard to predict, usually they dive when needed, which means when the fish farmers call on them.

A normal working day for a service company is very unpredictable and hectic. Even though the operation is the same, the days are usually different due to weather and other operational challenges. They have usually more than enough to do, and careful planning is almost useless because of unforeseen emergency situations. Most service companies operate within the approximate core time 7:00 AM to 15:00 PM, 17:00 PM or 19:00 PM, Monday to Friday, but the workers say they very often work overtime to finish the job. One company said they usually pick operations from the spot-marked, which means that efficiency is important to satisfy the customer. It is therefore also desirable to complete the job once they are out on site. If the job is not completed, it is usually the first priority to complete the job the next day. Delayed operations can depend on different factors such as harsh environment or emergency situations that needs to be prioritized.

Companies say it is less pressure when it is cold, due to less sea lice. Some sites could be up to four-six hours away from company base. It is therefore normal for the service workers to stay on the boat or on site if the travel time is very long. Even though the days are hectic, service companies state that *"everything becomes a routine with time"*, and that new people sometimes could be a stress factor, because they do not know what to do if something unforeseen occurs.

Operations will be further explained later, but the service companies say that the majority are inspection operations, such as net inspections and mooring inspections. It varies from company to company how they distribute the different operations. Some of the service companies says their days are quite the same, as each boat has their specific operations. Employees are usually attached to one specific boat over time. Others rotate their employees according to which operations, except from net cleaning. The washing team is usually one separate team, and very often not the same people driving the ROVs.

Several companies have a working system where workers are working x number of weeks, followed by numbers of weeks off. Several service companies operate with two weeks working 12 hours shifts, and then two weeks off. There are usually two persons per shift, one operator and one sailor. Another service company operate with one week working 12 hour days, and then one week off. These are just examples. Due to staffing, people working up to 24-hours shifts are only used when needed. It will only be carried out in special cases, if the customer is very busy and the completion of the operation is very urgent.

Most of the people who contributed to this master thesis had to use their own spare time, lunch time or evenings for interviews and questions.

4.1.2 Documentation during normal operation

Everything that is relevant for the customer, and general invoicing are documented. Huge or unforeseen deviations are also logged, but sometimes only internally. All service companies use daily reports electronically, and a few also do handwritten diaries. To have a computer available is therefore an important tool in everyday life. The reports can be in the form of regular daily reports, inspection reports, disinfection reports and safe job analysis (SJA).

Briefly described: SJA is a systematic analysis of various risk factors within a specific task or operation. It highlights all risk factors that makes it possible to take action to remove or control risk elements in preparation for, and during completion of the task or operation. Examples of sources for more information on SJA, NOG (2003) and Paaske

(2017).

It is also common to log into the maintenance system, in addition to different checklists provided by the employer. It is generally very common that the customer hand over an already planned operation to the service companies, and that the service companies do what the customer has planned. It varies whether the service companies bring their own equipment or not, but most of them do.

Without asking the companies about what reporting systems they use, one can assume that some of them use the same. Reporting systems that were mentioned are EQS, Infront-X, and Naviaq. Naviaq is still under development, but it has the intention to simplify billing, deviation documentation and more. Theory about EQS, Infront-X, and Naviaq are presented in appendix D page D-1.

Several boats also carry their own boat logs. This is done by hand, or on a computer, and is usually logged by the boat driver. When a diving operation is performed, they log into a standard form while operating. Here they log the time when the diver jumps into the water, what happens while diving, and the time when the diver reaches the surface again.

In relation to ROVs, it is common to do both pre-dive check (check of ROV before diving) and post-dive check (check of ROV after diving). The log for ROV operations is usually written after the operation itself, except for some companies that write during the operation. The report contains time-stamps for what they find and the depth for where they have been working. In addition, it is common to film during the operation. Log and video are sent to the customer after the operation, as part of the quality check of the work.

4.1.3 Use of supporting equipment and daily challenges

Data has already been mentioned as a valuable tool for the daily business. Another important factor is the boat. All service companies have their own boats.

"Occasionally I feel that we get some new equipment that are a little bit too fancy, but it has gone well. New equipment is important for feeling updated".

- Service worker.

With regard to equipment that makes daily operations easier and more secure, there has been several different tools in use. Tools related to electronics, digitization, locking systems on ropes, and better boats. In addition, to standard equipment such as chart plots and radars are in use. The companies state that upgraded equipment is a necessity to continue steady production, as the salmon needs both food and supervision every day.

One service company highlights the power block that they use on one of their boats as a very useful equipment. It saves them a lot of time and effort when it comes to coiling of rope and chains, compared to using a crane.

There is no doubt that all operations related to fish farming are weather dependent. An operation can take between half an hour and up to eight hours, and sometimes several days. Bad weather conditions could cause the operation valuable time, and make the implementation more difficult as unforeseen events can occur on short notice. The weather will in general be mentioned regularly due to performance issues throughout the whole thesis.

The desire for a better overview of what is happening inside the fish cages means installation of more disturbances inside the cage. These disturbances may adversely affect the operations, as it becomes harder to for instance navigate the ROV when it is inside the cage. Clean fish shelters and lights inside the cage can also cause equipment to get stuck, which is time consuming to fix.

4.2 Analysis of diving operations in the Norwegian aquaculture

It was more common before, having divers and ROV pilots employed in the same company. Currently, there are just a few service companies having both. To fulfill the requirement of having three divers available on board at the same time, they sometimes need to hire extra divers from other companies as well. Those companies only having ROV pilots hired, usually have some diving equipment available. They also have deals with nearby diving companies that can provide short response time in case of need.

At times it may be practical to have both divers and ROVs available. For those companies that have both available, it is desirable to mostly use the ROV because it is safer and more efficient. But if the visibility under water is too poor, divers are sent down instead. It is also very common to use the ROV to locate an error, and then send the diver in later. It is not common, but if it is very deep or difficult conditions, the diver can use the umbilical as a help to locate the error by diving next to it. One example on how a diver and a ROV could work together are explained in appendix B section B.2 page B-3.

The number of people on board will depend on the operation and who is available. The general rule of thumb is a minimum of three certified divers and a boat driver for diving operations, and two ROV pilots and perhaps a boat driver for ROV operations. Sometimes there are also some extra representatives present from the customer.

4.2.1 Divers

There are no specific requirements for divers, other than the regular diving certificate. The profession is otherwise characterized by a lot of "learning by doing", which is also the same for ROV pilots today. This will be further described in section 4.7 page 77.

Working day for a diver, and diving time

During the actual dive operation, the bottom time/diving time, is determined by the Norwegian Diving- and Treatment Tables, see section 2.6.2 page 26. The tables set limits for how long a diver can be under water dependent on depth, which means that they do not always manage to finish the operation. If one diver can not complete the entire operation, they usually continue with another one, which is one of the reasons why there has to be three available divers at the time, for each operation. Each diver can in many cases have repeated dives the same day, under the regulations given by the tables. After three days of diving, the diver needs to take a diving-free day.

"We can dive down to 30 meters, maybe 39 meters, before decompression is necessary. You can stay at the deepest depth around 10 minutes."

- Diver.

Examples of diving time: Diving at 30 meters without decompression gives 20 minutes in the water, 20 meters 45 minutes, 12 meters 165 minutes, and 6 meters 460 minutes. All this can be found in the Norwegian Diving- and Treatment Tables.

Diving equipment

It is usually only one diver in the water during operations, but it is still required to have two sets of diving equipment on board. The extra set is intended for an extra diver as a reserve, in case of emergency or if a diver get problems and cannot reach the surface on his own. All equipment must be certified. It is not that common to use an observation ROV to observe the diver during operations. Instead, they use a camera mounted on the divers helmet if necessary. Constant contact between the diver and the boat is crucial, unless it is a very short dive where the diver can dive without a mask.

Necessary standard diving equipment are wet suits, flippers, diving mask etc. In addition they also need a low pressure compressor and also possibly a bank bottle. Heavy helmets with communication possibilities should also be available. The divers say they have all necessary equipment they need, but that it is important to keep in mind that all offshore equipment not necessarily fits the need in the aquaculture industry.

The divers did not highlight any specific challenges with the equipment. What they did mention were the boats. The classification of the boats determines whether the boats are good enough to be used in more exposed areas or not. Most of the boats today are not good enough, they need to be more stable and maybe even of a bigger size.

4.2.2 Diving operations

Operational requirements

General requirements concerning diving operations have already been mentioned in section 2.6.2 page 26. As the section mentions, there are different guidelines and regulations given for the diving operations. Service companies can confirm that they use the NORSOK 103, EPA/WEA, and that they follow IMCA for safety reasons. They also follow the safety evaluations related to laws and regulations set by the company or the customer. All laws and regulations are in general set to assure safety for divers before, during and after a diving operation.

Each diving operation requires a minimum of three certified divers per boat; one who is diving, one stand-by, and one dive leader, in addition to the boat driver. Some service companies believe that in the future they will require four certified divers.

Although there are very few uncertified divers today, there are still some companies using equipment intended for sport diving. Equipment for sport diving do not satisfy the laws and regulations set for work diving.

Usual procedure

The usual procedure for a diving operation is one diver in the water at a time. Divers are often lowered by cages if they are to operate inside the net cage. If the operation takes place outside the cage, they usually just jump from the boat. Division of labour on deck is one person handling the air tube, one person responsible for communication between the boat and the diver, and one person responsible for communication between the one handling the air tube and the rest of the crew on the boat. Reason for the last one is because the one handling the air tube usually stands outside, while the people monitoring the operation are inside due the electrical instruments.

Every operation needs a dive leader, who is the one responsible for the direct contact between the diver in the water and the boat. Communication takes place via radio and very high frequency (VHF). The leader is also responsible for conducting a diving log along the way. The log is run on the computer, and it is a standard form that addresses the big happenings. Happenings like time stamps for when the diver gets into the water and up again, and space to note if anything unusual occurs or if they observe something that needs further consideration. The logs are stored for about 10 years, and used for normal logging and learning purposes if something similar would happen again.

Divers are usually contacted for net inspections, or for deviations requiring a gentle handling, such as holes, rope knotting and other detailed tasks. Net inspections are necessary before the fish is set out, while the fish is in the cage, and also after. When a diver is inspecting the cage it is usually done from the inside, where the diver follows the net and does a visual inspection. The advantage of using a diver is that holes detected along the way can be fixed at once. Another advantage is accuracy under inspection, but service companies disagree upon this as some ROV pilots will say the ROV is just a accurate. Some companies say that even though a diver has limited time under water, it is still worth it to use divers for inspections, because they get a better visual overview. Others say that they can see better with an ROV, as long as the visibility is good, and that they sometimes have discovered things that divers have not seen. Diving operations are in general a little more expensive than ROV operations, so whether companies choose to use divers or ROVs to carry out the inspection depends on purpose, need, and the chances of accidents that can cause loss of lives.

It has already been mentioned that it is not so common to have both divers and ROV pilots employed in the same company. According to the service companies, common procedure is that fish farmers/customer hire them for inspections with a ROV. If the service workers find any errors or other deviations, these are reported back to the customer. The customer is then responsible for contacting a diving company to fix the damage. If the damage or deviation requires both diver and ROV, the customer is the one responsible for arranging a new agreement on when to fix it. This indicates that divers are only contacted when it is necessary, which means that there are no regular routines for when diving is scheduled.

Operational time-frame

Time-frame for one net inspection will depend on fish cage size, location, number of nets, fouling, depth, and whether the diver uses a scooter or swims.

A normal net inspection usually takes around 30 minutes according to one of the service companies. If they do not have to sew holes or fix any damaged masks, another company says that a normal net inspection will take between 20-50 minutes. Most fish farming companies have several fish cages at the same locations, and it is normal for the divers to spend a couple of hours when carrying out net inspections.

> *"The inspection operation itself does not take so long. What takes time is to find the right location and to identify the problem, but there are of course always room for*

improvements."

- Diver.

Although divers say there are room for improvements, several service companies say the operation procedures are good enough today, and that they do not see any immediate improvement potential, except for better boats. The boats need to be more stable to reduce the weather challenges.

Another operation that requires some time is installation of mooring systems. This is an example where both divers and ROVs are necessary. One of the companies says that there is often a lot of diving in the beginning of at mooring installation operations, because of bolt drilling and chain mounting. They normally bolt until all diving time is consumed. After bolting it usually takes four to ten days to install and fasten anchors and ropes. In the end they go through all moorings and video tape them. The entire operation can take from one to three-four weeks.

Challenges and accidents

All diving operations are weather dependent, as will be mentioned for the ROV operations as well. Bad or extreme weather have often caused operations to be interrupted, and is a huge challenge to consider, when looking upon possibilities of going into more exposed areas. Strong currents could also be challenging. There are no specific rules or regulation when the weather is too bad, so each company tries to maneuver according to their own acceptable weather conditions.

Other reasons for interruptions could be oxygen cut, equipment failure or human failure. Freshwater and mountain water can sometimes be a challenge, because it causes humidity on the instruments, which may seem destructive or cause reduced performance. A diving operation will immediately be canceled if there is a risk of security breach. Fortunately this happens very seldom. Safety always comes first, and workers must therefore be able to make quick assessments along the way.

One common cause for accidents are panic. Divers perform a lot of training to avoid panic situations, and they also train for necessary emergencies.

4.3 ROVs

ROVs comes with a standard design in aluminium, but in almost unlimited kinds of sizes where the main difference is power measured in kilowatt (kW). Examples of normal sizes for the aquaculture industry are 3500kW, 7500kW, and 15000kW. The small ROVs could be approximate 1m x 1m and 400-600kg. Most service companies only have working class ROVs, since observation class ROVs only can be used for one purpose only.

"Observation class ROVs are too small to actually do anything. They are a waste of money.".

- Service employee.

A normal standard ROV has a speed of around 2 knots and is therefore considered more efficient for inspection purposes, compared to a diver. Another advantages is unlimited operation time. One serveice company says they only use the ROV for max. 1 hour at the time, but this will vary from company to company, and the environmental conditions.

To be able to fulfill the industry demand for ROV operations, most service companies have several ROVs. Some have three, others have up to five or more. Quick response time is important to many fish farmers, and may occasionally be the crucial factor for which service company to contact. Some service companies can confirm the use of this "first come, first served" culture, while others say there is no such thing and that they have more than enough work to do.

4.3.1 Reliability, vulnerable parts and repair

Reliability can be defined in different ways. In this case, reliability is assessed against operating time for a ROV when evaluating the quality and durability of the various components.

According to several of the service companies, ROVs are quite reliable and can last for several years. One of the equipment producers says they have delivered ROVs that have functioned for 18-20 years. The service companies usually choose one of the producers and stick to them, as their equipment are not compatible. All companies say they are very are very satisfied with the short delivery time.

"They are seriously reliable, and we have almost no broken ROVs yet."
- CEO, service company.

It is hard to decide which components are the weakest ones, because it will depend upon several factors as range of use of the ROV, weather conditions, personnel experience, and mobilizing of equipment. Most problematic is strong currents and vibrations. All in all, all equipment are exposed to damage, but some more than others.

The most vulnerable parts are the cables and the contacts. Damaged connection contacts can easily be fixed during operation if there are spare parts available on board. It is not that critical, despite the fact that it often happens. Contacts needs extra attention, specially those for lights because they are shorter and smaller, and therefore more vulnerable. Water penetration is a common problem, and the contacts must therefore be kept watertight.

The umbilical, and data card could also break or suffer from water penetration, forcing the service workers to pull up the ROV and cancel the operation. These are the two most critical failures along with the thrusters. Fixing of the umbilical could take hours, because they need to take the umbilical up from the water and solder it. Then they might have to caster new fiber contacts. Umbilical and thrusters can mostly be fixed by the service companies themselves, but if a data card gets damaged the ROV needs to be sent to the ROV producer for service. Causes for card damages could be water in the main storage where all the cards are located. If this happens, the ROV is useless until the problem is fixed.

The actuator (a device converting energy into motions) is also mentioned as a weak spot. One service company said that the actuators have a production weakness, and that the sealing device is very easy to break.

The plug fuse can cut if the ROV touches any clean fish. This could either be repaired in the water by resetting the ROV, or sometimes they have to take it up for further maintenance. The ROV can still be used even though the fuse has cut, but it will be very slow.

"We always try to complete the operation, even if minor damages should occur, as long as they are not essential to the operation or violates the safety requirements."
- ROV pilot.

Usually, if the damage is very small, the ROV can still be used. For example if the lights stop working they can continue, given that they can still see something, which will depend on the depth. It can also continue despite defect compass or depth meter. A ROV is often equipped with four engines for moving forward, backward and sideways, as well as two motors that provide movement up and down. It is not necessarily critical if one or two engines break, but it depends on which one, and environmental conditions at the time of the break.

The list below shows some situations where they can not continue to use the ROV:

- They loose photo/video from the camera.
- Video card gets broken.
- If a thruster stops functioning, dependent on the situation.

Most service companies do have some spare parts with them in the boat on missions, while others have them onshore. Most repairs are quick, and plenty of them can be done by the service workers. The ROV is usually ready for operation the next day. If the service workers can not fix the problem themselves, the service company needs to send the ROV to the equipment producer, or the equipment producer has to send out someone to the service company. Equipment producers can sometimes fix data errors from their own office by logging on to the customers system, and check the ROV condition.

It is generally very expensive to have spare parts stored over time. Most spare parts are therefore ordered when needed, and service companies say this is not a problem as the equipment producers have a quick delivery time. If they order at the right time, spare parts could be available as early as the next day. More about costs in section 4.9 page 79.

4.3.2 Maintenance, service, and other procedures

ROVs require a lot of maintenance according to one of the service companies. How reliable they are will depend on the precision of the maintenance. Regular maintenance is both important and necessary. The contacts need to be lubricated, ground fault must be fixed, engines need oil, and it is important to avoid disturbances on the camera lens.

The electronics are well protected by the aluminum housing, and errors here will according to the equipment producers, usually be because of carelessness in the maintenance procedures. Plenty of the components can be switched out and should be, after some years.

Regular maintenance is standard procedure, after use and when needed. Several companies also do a more thorough maintenance every other week. Daily, weekly, and monthly maintenance are performed according to given checklists. How often weekly and monthly maintenance are performed varies.

Several service companies have a service interval of twice a year, were they send the ROVs to the equipment producer for a more thorough service check and upgrading etc.

"The ROVs have less defects when they are in frequent use. It is therefore better to use them almost every day, instead of having them stand-by."

- ROV pilot.

Drying of ROV can lead to salt weathering, which can have negative consequences especially for the contacts. It is important to wash the ROV with freshwater after each use to avoid equipment damage from salt. Normal procedure is to visually check the ROV every morning before use, lubricate all contacts if necessary, and check that all engines are still fixed and have enough oil.

4.3.3 Equipment

Standard equipment for a ROV are among other things lights, cameras, heading index, sonar, and different software. The ROV can also register depth and heading, which makes further documentation easier. Some ROVs can also record compass direction.

An extra equipment that several companies make use of are a robotic arm that needs to be operated manually. Functionality of this robot arm will vary according to whether the arm is mounted by a ball joint or not. Some companies just have a very simple arm that can close and open to pick up things, or they can set up a scissor in front to enable cutting of ropes. Figure 4.1 shows an example of an arm to the left, and the scissor to the right.

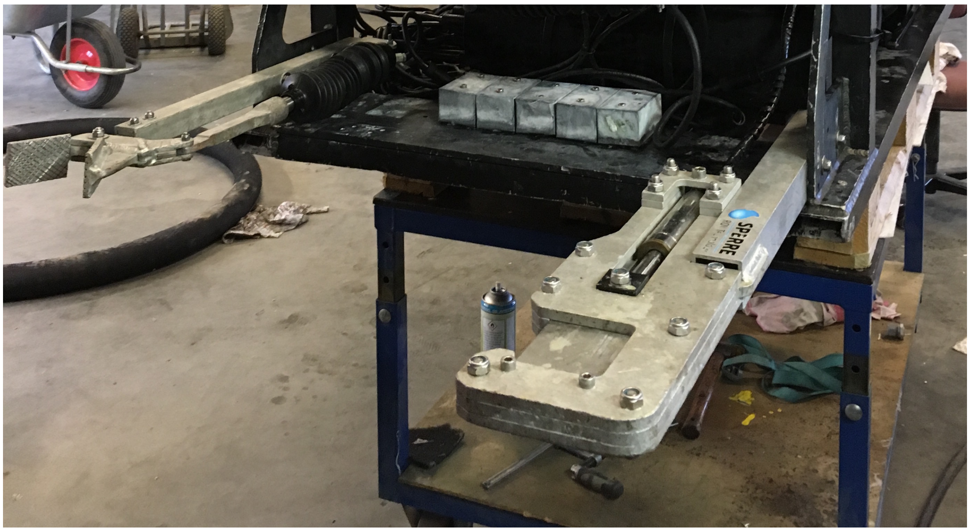

Figure 4.1: Robot arm and scissor (taken on field trip).

These arms usually have a fixed length. The robot arm is not necessary for observation purposes, but on the other hand very handy when attaching pipes and ropes. Important to have in mind is that the robot arm can not fix complex problems, and the scissor can not provide very much power except from cutting ropes, so none of them are very useful for bolting or tightening of ropes.

Several service companies say they have skilled mechanics who have fixed their own "self-made" functional solutions that the company use. One example is a new attachment mechanism for better mobility of the arm.

Sperre AS has their own sewing machine that can be attached to the largest ROVs. The machine is quite big and the purpose is to assist with an alternative to fix holes in the net without the assistant of divers.

In addition to physical equipment, some digital programs are also adequate for safe operation of the ROV. *Oleks map* is a map showing the position of the boat. This could be used together with the HPR system, which is a tracking system connected to the ROV. The HPR system sends signals to a receiver attached to the boat, and makes it possible to always know where the ROV is located relative to the boat. The driving route of the ROV can therefore be tracked and saved, and sent to the operator.

4.4 Analysis of ROV operations in the Norwegian aquaculture

ROV operations are carried out by service companies, and it is highly essential at greater depths where diving time creates a noticeable limitation for the divers. As already mentioned, service companies usually have several ROVs to be able to conduct more than just one operation at a time, and also in case of failure or emergencies. Still most of them only have one ROV on each boat. This is due to lack of space since most boats are less than 15 metres. It is also very expensive to carry several ROVs in case of accidents.

"If the boats get bigger, we will also be able to bring more ROVs at the same time. Currently it works fine bringing just one, and I do not know if it's really desirable to bring more. It will be very expensive if an extra ROV would get damaged just by standing there."

- ROV pilot.

4.4.1 Operational procedures, decision making and responsibilities

Normal operating routines requires two to three service people, depending on the operation. It is only necessary with two people if the boat is moored during operations, one to steer the ROV, and one to take care of the umbilical. If the boat needs to move while operating, a boatman is also required. All operations are documented, either during operations or after. Video-filming is also common, especially when they find deviations.

Service companies usually get all necessary information from the customer, including important phone numbers, information about the operation (if necessary), and a map over the fish farm facility, either beforehand or when arriving at the site. The service workers use the map to plan where to start, to make the operation as efficient as possible, time saving and effective, and to avoid dragging unnecessary umbilical through the water. In addition to the map, companies usually do not carry out any specific data acquisition. The "only" thing they do is to regularly check the weather at *yr.no*.

Most operations are carried out on "autopilot", which means they were carefully planned the first time, and that it becomes a routine after that where everyone knows what to do. Special assignments are planned beforehand. Service managers and operators are those who make different decisions during operation, but the customer / site manager has the final word. On paper, the operational manager is in charge, but in practice there are no specific person in charge on the boat during operation. Everyone involved decide together what is the best solution if a problem occurs.

> *"The location manager does not always have so much experience with ROVs and mooring jobs. They usually listen to advice from us."*
> - Service worker.

There is generally little communication with those on land during operations. Many service companies have a morning meeting, but when the boats first leave, the crew makes their own decisions.

They all have different responsibilities during operation. It is common to rotate on most tasks, so if one gets sick, anyone can take over.

4.4.2 Documentation during operation and risk assessment

All operations are documented as a log or report after implementation. These are kept for learning purposes, documentation and sent to customer. During operation they video tape everything. A few companies do risk assessment and logging under the operations, but most of them say they do no specific risk assessment before the operation is done, but that they are taken along the way. Service companies are required to document all deviations.

As mentioned, no companies are required to carry out any risk assessment before starting the operation. Several still do, and have made their own risk assessments for the different ROV operations. All of these are sent over to the Directorate of Fisheries for assessment and approval. Companies also have their own procedures for maintenance and SJA.

4.4.3 Challenges

The majority of operations usually take place as planned. It happens that the umbilical gets stuck in different things. This is not critical, but creates a delay in the operation. Each and all of the companies connected, agree that weather is the major challenge for ROV operations. Bad weather can cause delays that over time can give unfortunate outcomes. Too bad or extreme weather will simply create too much imbalance and make it hard for the crew to operate safe and precise. The operations can then cause more harm than it does well.

"The weather is for sure the biggest challenge, and maybe also the only thing stopping us."

- ROV pilots, service workers.

Big waves and strong winds, everything happening above sea surface are of major relevance for operations on the sea surface. Operations as launch and recovery of ROVs, docking, delousing and etc.

Operations under water such as diving and ROV operations after launching are mostly influenced by strong currents. What happens on the surface does not directly influence the equipment under water. The moon cycle determines when it is low tide and high tide, and too strong currents can arise every sixth hour, which is frequent. What is challenging with strong currents are that the net has more unforeseen movements.

Water conditions can cause visual challenges for the ROV. Brackish water, which is a mix of freshwater and saltwater creates bad visibility in the upper layer of the water. Water in layers and depth will also enhance bad visibility. Sometimes operations are easier to implement during the winter, because colder water gives less algae and better visibility.

According to several of the service workers, the boats create a challenge, because they are a little bit too small and unstable in rough weather. Some of the boats may struggle with humidity that will affect the equipment displaying different ROV registrations. At times, the humidity may be so bad that the equipment are not working properly. There are also some new requirements for the boats, which means that a number of service companies have had to stop using some of the boats they have. Nevertheless, there are some boats used today that are on the limit of being approved.

4.4.4 Critical ROV operations

General routines for the different operations are controlled and very dependent on weather, wind and surroundings. Lifting operations are for example very complex. These are very vulnerable to weather. Especially with regard to safe operations for humans, fish and fish farm facility. The counting of sea lice is also very sensitive to bad weather, and it can get critical if it has to be cancelled several times over.

All ROV operations are necessary somehow, and it is therefore hard to pin point the most critical ones. But the launch and recovery part have been mentioned as very critical, because the ROV is brought down very close to the boat's gunwale. It is lowered by a crane, and large movements will make it unstable, and create uncontrolled pendulum movements. The ROV can then crash into the boat, causing damages to the ROV or the boat, and also increase the risk to the crew by increased risk of squeezing.

Driving the ROV below objects could be critical if the ROV gets stuck, or if the engines dies. Usually if a ROV happens to die or stop functioning, they can just pull it up by the umbilical. But if it is stuck below any objects, that could be a critical situation.

There are no written precautions to minimize the critical operations, other than regularly considering the weather and use of common sense during operation. The golden rule is that every operation is cut off once they go beyond the safety of personnel or fish.

4.5 ROV operations

Inspections are the most frequent operations, such as net and mooring inspections. These checks are highly necessary and needs to be done annually.

When it comes to given regulations, it seems like the service workers do not know about them. They do believe that there are some given regulations for use of protective equipment, but that it is in general the fish farmer's responsibility to check the regulations. More about general safety management i section 4.6 page 76.

As already mentioned, weather creates the biggest challenge. An operation is rarely interrupted because of the equipment. Difficult weather conditions are the main reason for operational interruption. When an operation is interrupted due to the weather, they wait until the weather is better. If it does not show improvements the same day, they go back to base. Finishing the operation is then set as first priority the next day.

4.5.1 Net inspection

The purpose of net inspection is to check for holes and other deviations that might lead to fish escaping. It is one of the most frequent operations, and each operation has its own requirements set by the fish farmers.

Execution of the operation

Standard procedure is to first do a pre-dive check of the ROV before launching it into the sea cage. The ROV then drives around inside the cage and checks that everything is okay with the net, that no holes and no other breakages exist. After the inspection they do a post-dive check of the ROV. Pre- and post-dive check are general inspections of the ROV to check that everything is working fine.

The ROV is generally very close to the net during inspection. The golden rule is that there should be nothing between the ROV and the net during inspection to intrude the visibility. In case of particularly poor visibility, the ROV can be as close as 0.5 meters. Usually the distance is 2-3 meters. Too long distance will make it difficult to detect if anything is wrong.

> *"We are not touching the net, even though we are quite close during inspection. Still we have not managed to make any holes with the ROV, but it is normal to fracture a mask or two."*
>
> - ROV pilot.

Net inspection is a time consuming operation. It can vary from half an hour to three hours, depending on visibility, amount of cages, and cage size. Average time is about two hours.

Fish farmers are responsible to book the service companies for net inspections frequently enough. Some companies say it should be done every third month, others say that it could vary from every 14th day, to just once a month. Service companies can not control how often the inspection is done.

Weather is the biggest challenge, and especially strong currents. They make it hard to navigate the ROV and keep it in position. Even though most ROVs have heading installed, which allows them to keep it at a certain depth.

Sea conditions could be a challenge for the visibility, but it is most critical near the surface. Another factor is type of water. Freshwater is more difficult compared to salt water. Winter is also easier when considering the visibility.

Another challenge is darkness. Sometimes they need to interrupt the operation because the fish gets too attracted to the lights or stressed. To avoid this the service companies tries to use low-ligt cameras, or LED lights that can be used at low intensity. How they deal with this challenge will depend on the fish farm, fish, and location.

Everything that is in the cage will also create challenges. The ROV can get caught in whatever floats around in the cage: Cameras, hiding places for wrasse, and ropes. This happens rarely though.

The majority of service companies say the operation is good enough today and that they have the equipment they need, but that better cameras would help. They will help increase the accuracy of the operations.

Deviations

- Holes in the net, or fractures.
- Splicer in net.
- Gnawing: If something lies against the net and wear the net.
- Defects around the bottom ring fastening point.
- Placing of the net, bottom landing net and bottom ring.
- Too much dead fish.

Fractures happens from time to time, and as mentioned, the ROV could cause them. Only one fracture is not that critical, because the fish can not escape through one fracture, but wrasse can.

Holes are rarely found. The reason may be that the landing net has hooked onto something that should not be there. There have also been some cases were bigger fish have bitten through the net from the outside to get in.

Any deviations are resolved as soon as possible after they are detected. Typical for deviations related to net inspection are that they require divers for repair. Especially holes, as they need to be sewed by a diver. If the holes are near the surface, no further than three to four meters, they can take up the net and fix it from above. As mentioned, Sperre AS does have a sewing machine, but it has not been tested properly yet.

"The sewing machine is not really tested, but we want to try it more. Currently we have only taken parts from it. The reason why it is not used is because it is big, making it inconvenient to bring along."

- Service worker.

If the net inspection is conducted by divers, they can fix possible holes at once, but if the inspection is done by a ROV it can take up to two hours before the divers arrive. One service company says that to prevent fish from escape they place the ROV in front of the hole until divers arrive. Normal procedure is that the service company notify the fish farmer, and that the fish farmer calls for the divers.

Holes are most likely to occur in the sides, which allows the service workers to repair it without divers. The net is then lined up and repaired at the surface. This is also cheaper. Divers are mostly required if the hole is in the bottom.

Advantages with ROVs compared to divers

Companies disagree about which method is the best one, divers versus ROVs. An inspection with divers will probably take less time, but require twice as many people to cover the whole inspection because of limited diving time. There are some service companies who only offers net inspection with divers, and not ROVs, because it is faster. Important to keep in mind is that a diver can only have a certain amount of dives a day, which means that one inspection most likely will require several divers that will indicate higher expenses.

ROVs are therefore cheaper for this purpose compared to divers. In addition to being more accurate, have lower risk, and unlimited diving time, the sea condition could be a challenge sometimes. It is easy to spot holes with the ROVs, and sometimes they also spot holes that divers have overseen. Some service workers believe that limited diving time could weaken the divers ability to spot deviations.

4.5.2 Mooring inspection

The purpose of mooring inspections are to check for deviations along the line, around the moorings, and at the bottom.

Execution of the operation

The crew launch the ROV into the water. Then they follow the mooring line from top seal to bottom seal. The customer usually requires them to video tape it all and send it afterwards, which is also very helpful for documentation purposes. Necessary ROV equipment for this operation are sonar equipment, positioning equipment, sometimes a gripping arm, and camera.

When following the mooring line with the ROV they check that nothing lies against is. They also check the splinters and everything else connected to the moorings. They usually get info on the number of meters with chain, rope and etc. from the fish farmer.

The time-frame for implementation depends on the number of lines and the length of these. Difficult weather conditions like strong currents will also increase the time usage. At a normally large facility the inspection will take about one day, or maybe two-three days. A total inspection on a very large farm may take up to one week, which is very long. The operations are required to be done frequently, and every fish farm facility are required to at least do a two-year control on the mooring systems where they check each line, anchor and bolts.

The moorings they inspect can be bolted to mountains or dug into sand banks several meters down. General mooring line inspections should be done at least once a year, although the regulations say it should be done two times a year. It is up to fish farmers how often they think it is necessary.

It does not matter if the fish farm facility is of the ring or steel type, the challenges are the same. Strong currents have already been mentioned, as well as high and big waves. Big waves on the surface will make the boat unstable, and create more difficult operational environment for the crew. General boat traffic in the immediate area also creates a risk factor.

All in all, all companies believe that mooring inspections are good enough the way they are carried out today, but that there are better equipment available. More accurate equipment for example. Whether better equipment is necessary or not, will depend on price versus need they say. Right now they do believe they have what they need.

Deviations

Typical deviations are:

- Ropes that are in contact with the bottom, mountains or rocks, i.e. the rope is on the bottom before the chain.

- The ropes can rub on each other or have twisted errors around the splicing.
- Ruptures or overlaps.
- Wear and tear of chain, rope, and junction points. This is very common, and the reasons for this can be chain corrosion or that the ropes are located at the bottom instead of free floating in the water.
- The transition between rope and chain consists of trawl knots that needs to be checked.
- The location of the anchor is incorrect.

It varies how often they find these deviations, but ruptures and overlaps are most common and are discovered often.

If a deviation occurs, the fish farmer is informed. The severity of the deviation will determine how fast it has to be fixed. If the boat that inspects is able to fix the deviation, they correct it on the same day after completion of the inspection. Either by use of the ROV or by pulling up the rope. On the condition that they have the necessary equipment available.

If they do not have the necessary equipment available, a service boat or divers must be contacted. This is the fish farmer's responsibility. The fish farmer must call a service boat to fix the deviation, and then schedule a new appointment for the ROV to inspect again after the fixing. The best solution is to have both the fixing team and the ROV team present at the same time. This will be time-saving, as the ROV can check the repair immediately after diving.

Advantages with ROVs compared to divers

Mooring inspections can be done by both divers and ROVs, but divers are limited by depth. Advantage with ROVs are that they can go down to unlimited depths as long as they have enough cable. Several ROVs can go down to 500-800 meters. Another advantage with ROVs are that they can cover a larger area since their operational time is unlimited by the umbilical. The ROVs are also powered by the boat and can i theory operate for days at the time.

Divers can only inspect some parts of the mooring lines as they go too deep for them to dive. They can inspect down to the mountain bolts, but since the lines are often very long, it is more practical with ROVs to do the whole operation.

Frame moorings can be inspected by divers, but ROVs will probably be an advantage here as well, as these moorings have long distances.

Fieldwork

Note: This field trip has been written in I-format.

One of the field trips was to a service company, who does all kinds of ROV operations within aquaculture. I arrived at the airport around 7:00 AM, and one of the workers picked me up and drove me to the working place. As for the first company visit, these also started the day with some kind of morning meeting. The atmosphere was very light and calm. People were small talking and drinking their morning coffee. No stress was observed.

Since I arrived a little bit early, one of the workers gave me a round trip on the working place, sharing knowledge about the company, their customers, what they do, and also showing me the workshop where they keep their spare parts and maintain their ROVs. He also showed me the sewing machine produced by Sperre AS that can be fasten to the front of the ROV. The sewing machine is meant to fix holes in the net, but this service company have not yet tried it out, because they think it is a little bit inconvenient due to its size. The service worker said it seemed to be a good tool, but that he did not have any experience with it. Several questions from the interview were asked before leaving the base.

A normal day usually look like this:

1. The customer call the service company and tells them what kind of service they need, how urgent it is and what they have to do.
2. When the deal is arranged, the customer send over all necessary information such

as an overview of the facility or the mooring systems if they want a mooring inspection.

3. The workers have a morning meeting for those who want to. Usually they have already split the teams, and the teams get instructions individually.

4. They drive out to the facility, this could take from 1-5 hours. If it is very long, they usually sleep over.

5. When reaching the location, they launch the ROV, do the operations, and take it up again.

6. Documentations are done afterwards, and reports and videos are sent to the customer as proof of the work.

Today the assignment was a mooring inspection on a quite new fish farm facility. It took about 1,5 hour to travel, which gave a lot of time to ask questions from the interview guide. Of curiosity we first visited the fish farmers at the facility, getting a tour around to see this new "building". The fish farm had several ring cages, but not all was in use yet.

The service workers had already a map over the mooring system, but had been informed that is was not necessarily correct. They were two service workers, one to control the umbilical, and one to steer the ROV. There were no need for a third one, since the boat could be attached to the moorings during inspection. The umbilical was automatic, and the work on deck seemed in general very relaxed. The weather was good, except from some rain at the end, but that did not influence the inspection. They did not use any radio for communication, but there were radios available in the boat that they would have used if the weather was bad and normal talking was not enough. The worker steering the ROV just followed the anchor line with the ROV, filming and spending some extra time around the joints. It was in general less communication here compared to the first service company.

The inspection went well, but it were some delays. There were some strong currents at a few places, making the video quality poor. They solved this quickly by doing the inspection once more. Also other service boats were operating at the same time, causing some delays due to logistic. All in all, they were almost done on scheduled time, and we were back on land around 5:00 PM.

4.5.3 Net cleaning

The purpose of net cleaning is to clean the net for fouling and other unwanted factors.

Execution of the operation

Several service companies uses a MPI-rig called RONC for cleaning purposes, which is a type of crawler, see section 2.7.2, page 30. Common for the service companies are to have their own washing team to handle the RONC, these are not the same people as operating the ROVs. One company says they do not use RONC anymore, because of the wear and tear it caused the net during operation. They mention that Sperre AS has developed a remotely net cleaner called FNC 8, but that they have not tried it yet.

According to the equipment companies it also exist a flying net cleaner that is only used for washing. It is a combination between a RONC and a ROV that can crawl and fly. Flying makes it more gently for the net. The net bottom is usually washed with a ROV.

The cleaning procedure can take from one-two hours and up to several days, depending on size, amount of fouling, current conditions and position of the net.

Frequency and need depends on location. One service company says that it could be as often as every fifth day during the summer, but that the interval normally is around 10-14 days. It is more seldom in the winter period. Another company stated that the operation is done every 14th day.

No shock, the weather also creates a challenge for this operation. A lot of waves make the operation hard to complete. Washing at ring farms are easier compared to those of steel, because the workers can walk around the facility. Another challenge is that the operation causes damages to the net, which are not good over time.

When it comes to quality of the cleaning operation, several companies say it is okay in view of the available equipment, but that there are better equipment available. One company says that the equipment is not good enough, and that several suppliers are working on developing better solutions. The fish farmers are also requesting better equipment.

Deviations

- Holes caused by the belts from the net washer.

If the holes are discovered during washing, divers need to be contacted to repair them. The procedures for holes during washing are the same as for normal net inspection.

Advantages with ROVs compared to divers

The ROV is faster and cheaper compared to a diver. Divers can also do net cleaning, but it will be very time consuming and it requires the divers to be under water for a very long time. For most companies this is not a question, since they usually use the specialized washing rigs.

4.5.4 Other operations

ROVs are usually used for observation purposes within aquaculture. In addition to the mentioned operations above, they are also used for assistance during anchorage and rope handling, where they observe that everything is done properly and without any major mistakes.

Pipeline inspection

Pipeline inspections are done similarly to mooring inspections. They find the pipeline and follows it until they discover deviations. Deviations could be holes creating leakage. A pipeline inspection was observed during fieldwork, see section B.2.

Delousing

Delousing can either be done by using a tarpaulin or fish carrier. The tarpaulin method requires around three hours and the ROV is used for observation purposes. A fish carrier needs around 24-hours, and the ROV is here used to check the net for deviations before and after operation.

This operation is done whenever is it required, but less necessary when it is cold. Unwanted consequence is unnecessary fish death. Weather is also here creating a big challenge. Another challenge is that when using a tarpaulin the ROV needs to do the observation from the outside av the cage where there are a lot of ropes. The ROV can get stuck.

Standard procedure when using tarpaulin is first a pre-dive check before the ROV goes down and check the condition at the net bottom. If necessary they adjust the weight etc. Then they check that all ropes attached to the tarpaulin are okay to avoid stressing the fish. The ROV is then used for observation of the fish while the tarpaulin is pulled up and dropped down. Negative occurrences could be that the fish is squeezed to death, but this negative effect is not caused by the ROV. Finally they do a post-dive check.

4.6 Safety management

ISO and other given regulations are followed as part of the general safety management. Several service companies can confirm that there are no written rules or regulations for how operations are to be carried out. In general, they believe that regulations are an advantage as it gives equal demands to every companies. All boats are ordered to follow the regulations given by the Norwegian Maritime Directorate.

As part of the safety management, several service companies have their own internal procedures that all employees are informed about. Customers also set their own premises and requirements when service companies operate for them. When working on deck they are required to wear protective equipment that includes vest, helmet and safety boots. Fish farmers set these requirements, and service workers must follow them. All workers have their own safety equipment, as it is personal.

4.7 Required training and follow-ups for ROV pilots

Working with ROVs touches several disciplines such as cybernetics, electronics, computer knowledge, and high-voltage. It is important that everyone gets to know the equipment, nets and mooring before they can drive ROVs. ROV pilots are also often responsible for operation and maintenance of the ROVs.

"There are no specific rules for who can drive a ROV. Everybody can with some training, but you must have a certificate of boatmanship."
- CEO from service company.

It is especially important that pilots operating the ROV during net inspection have some experience, so that they do not make "beginner mistakes". As for instance driving with open rope cutter or other sharp objects mounted. It is very common that all workers know about all operations that the company can offer. The service workers usually rotate on the tasks, which means that most of them have been through it all. The diving itself requires certified diving licence and special experience, but all other tasks can be rotated. This is very handy, because if one is ill, another may step in regardless of the task. The quotes below applies to several companies.

"I think that experience is very important in the job we do, especially knowledge about moorings. Mooring inspection is a very dangerous job if you do not know what you are doing. We do very heavy lifts with cranes, in addition to rope tightening up to 30 tons."
- Service worker.

"In our company, everyone does everything. This is good, as everyone should be able to do everything that the company can offer."
- Service worker.

Workers within service companies have different backgrounds, but most of them are skilled workers, engineers or service workers. The composition of employees is therefore very varied, as some of them have several years of education from mainly automation, electronics or ROV subsea operator. Or they could just have finished high school, taken a bachelor or a master. Others have more than 20 years of experience, gained from different platforms such as a slaughterhouse, processing of salmon, service boat, or fishing. It is not unusual that workers are strangers to the fishing industry when starting. Some have backgrounds as car mechanics, machinists, teachers, etc. Several of them have therefore participated in training at varies equipment producers or at courses within the company, and a lot of them are also self-taught.

"This profession is characterized by a lot of learning by doing. It is very fun to work with ROVs."

- Service worker.

Follow-ups are mainly implemented through the "learning by doing"-principle, where the less experienced get training from the professional ones. Other used methods are web course and seminars. Workers are also internally and externally taught about regulations, report writing, documentation requirements, etc.

4.8 Cooperation with other companies on site

All service companies carrying out ROV operations say they can work independently of the site's crew, and that there is in general little communication with the site during operation. As mentioned, the task description has usually been sent out on email with necessary information. If not they meet up with the crew at arrival, but that is the only contact they have.

"fish farmers in general do not really care about what we do, as long as we do the job properly. They tell us what to do, and we do it."

- Service worker.

Cooperation with other diving companies have already been mentioned, especially when deviations are discovered through net inspections. They do not necessarily have to be on site at the same time, but having both working teams there will make it more efficient and time-saving. Challenging for the fish farmer can sometimes be to coordinate a time that fits both schedules.

Cooperation with other service companies are essential for operations like delousing, anchor handling and tightening of moorings. Distribution of responsibility and general coordination is usually quite easy, because each company have their specific areas of responsibility. They have fixed tasks and people know what to do. Project managers, operations managers, and other governing people have meetings before operation, so everyone is informed about how the operation will take place. Communication goes through VHF and UHF, where VHF stands for very high frequency while UHF stands for ultra high frequency, they are both radio signals.

"Collaboration is usually good, as we often cooperate with companies and customers we know and have worked with before."

\- Service worker.

Normally, cooperation makes the implementation of operation easier and more efficient, because there are more people specialist on different areas present. But at the same time it could make the operation harder to carry out, because there are several companies and people to organize. The aquaculture industry is very hectic, and it can often be difficult to coordinate a time that suits all involved companies.

All in all, working with others goes well, people know each other and the atmosphere is good. There are in general mostly Norwegian workers employed within this industry, but some companies have international workers. These can sometimes be difficult to cooperate with, because of language barriers.

4.9 Economical cost and need

Two service companies say that today's technology allows ROVs to handle all kinds of operations, but that some operations may not be done as well as they should, and that is will be expensive.

All other companies say that they currently need both divers and ROVs and that type of operation will decide what is preferable. ROVs are not able to do all kinds of operations, such as knotting of ropes. Divers can in theory perform all kinds of operations, but there are some operations requiring too much time under water, and also the depth has become a significant limitation in the past years, making some operations almost impossible.

The big question: "Economical cost vs. need" is very interesting in the aquaculture industry. Some will say that the industry is more than willing to try new things no matter what the cost is. But it has already been mentioned that the industry is a little bit stingy. ROVs are very expensive vessels, and some companies are reluctant to try new things because if something goes wrong, it could go really wrong. In addition to equipment being expensive enough. New things are a bit scary, and no one really wants to be first, but at the same time they do. Because being first out with something new and better, make the company more in demand. One thing that fish farm companies, service companies, and equipment producers agree on is that if the industry want to go more offshore, they need to be more open to try new things.

4.9.1 ROVs

ROVs are expensive and can easily cost 1-4 millions Norwegian kroner (NOK). The equipment producers say they customize a lot of equipment, and all agree that currently they have what they need of equipment, but that there are for sure better solutions out there. For instance will contacts made of titanium be more robust and reduce a lot of contact problems.

One equipment producer says that from an economical perspective, ROVs are cheapest to produce as they are today with a box-shaped design in aluminum. ROVs are not dependent on very high speed, and the box-shapes is therefore fine. Any new design is therefore not a priority issue as this will be expensive. The buoyancy block is one of the most expensive components on the ROV. This is because it is made of syntactic foam, which is a special product.

Spare parts and repairs are expensive, which is why service companies do not want too many spare parts stored at their location. One of the most expensive parts to repair is if a data card is damaged and the ROV needs a new motor control bottle that can cost about 3500 NOK, just for the bottle.

"No components are so expensive that replacement will be more expensive than buying a new ROV."

- Equipment producer.

4.9.2 Diving and ROV operations

Service companies agree that fish farmers choose whatever is most convenient for the given operation, but that cost and response time are the two most deciding factors when they choose whether to use divers or ROVs, but they do not agree on which one is the most crucial one. Type of operation is also deciding, but today there are some operations that only divers can do etc. Some service companies believe that fish farmers think more response time in preference to cost. Specially when it comes to repair damage, such as holes that can lead to escape of fish. Others mean that cost is most important, and that several fish farmers choose ROVs first because it is the cheapest option, and also because they have unlimited diving time.

Operations carried out by divers are more expensive than ROVs, because of diving time. A normal net inspection could cost up to 30-40,000 NOK for each dive when using divers. For other operations cost is around 3750 NOK for one boat with a boatman plus one more. In addition comes cost for diving time of the diver or divers.

ROVs are therefore more cost efficient compared to divers. Cost varies from company to company, but most of them take from 3000-3500 NOK per hour, and from 25,000-30,000 NOK for 24-hours. Cost will also depend on which ROV they use, how many people needs to be available, and what kind of extra equipment they need for the operation.

4.10 Future thoughts

The aquaculture will for sure be very important in the future as well. It is said that the volume will have an outstanding growth on short and long term basis. The general interest for the aquaculture industry increases, and there are a growing demand for both salmon and trouts. The industry is constantly working on improving their methods. Not only for implementation of different operations, but also on how to get rid of salmon lice in a more gentle and profitable manner. Salmon lice and other diseases are according to the different companies the biggest issue for the future.

4.10.1 Moving into more exposed areas

The fish does not really care where it is, but it flourish continuous stream. Too demanding stream will have negative effect due to the fish capacity and cause stress in the cage.

The companies believe that it will be more focus on environment in the future, and that safety will be a huge focus point when moving into more exposed areas. Norway will most likely also get more competition from other countries.

There is no doubt that the industry wants to expand into more exposed areas, and here are some of the thoughts from the different contributors:

"This is good for the environment, but challenging for us as suppliers."
- Equipment producer company.

"I believe that the biggest challenge of moving into more exposed areas are that the routines needs to be the same, but that the weather will create even greater challenges and give larger limitations."
- CEO from service company.

"I guess it will be okay, and that the equipment that we have are good enough. But the boats need to be better fit for the exposed environment. I trust the ROV equipment more than the boats."
- Service worker.

Researches disagree. They say the industry is not ready yet and that the equipment would not handle it. The harsh weather will make it very dangerous to do launch and recovery that will cause danger for the operators, even though the ROVs are good enough. They believe that better winch systems can solve the cable handling, and that wireless ROVs could be a solution if underwater dockings are developed. Underwater dockings will decrease the amount of launch and recovery operations.

4.10.2 Education for the service workers

In terms of education, there are a few companies who believe that the requirements to be allowed to drive ROVs will be stricter in the future. They are all in general very pleased with their workers. Some companies wish that in the future, there will be an education specializing on the operation field, which will lead to certificate of apprenticeship within the field of ROV operation.

"What could be a challenge with an education is to find the balance between academic and practical learning. We are in general looking for the worker, and not the academic in this profession."
- CEO form service company.

4.10.3 ROVs and extra equipment

The industry is demanding better and more effective solutions at all times, reflecting the growing trend of new products and services. This create challenges for the equipment producers, as development takes time. Also the industry have several employees with limited technical knowledge, slowing down the process. Some service workers have already mentioned that they sometimes feel that the equipment are a little bit too fashionable. The equipment producers says that the industry in general are very willing to try out new solutions, and they hope they will continue to be.

"ROVs have come to stay. The technology is relatively new, and there are always room for improvements."
- Service workers, equipment producers.

"We may have to make some equipment more robust, but that is not a proble."
- Equipment producer.

The equipment producers deliver quite big and robust ROVs today, and they believe these will be good enough for more exposed areas as well in the future. What the industry probably will have to change are the boats and handling system for the ROV.

The boats needs to be bigger and more like the offshore vessels. For the handling system, an A-frame might be necessary, but that will also be very expensive.

The ROVs will probably become more autonomous with time, and continue to be electrically driven, but with hydraulic extra equipment. Hydraulic driven ROVs will cost from 6-30 millions NOK, and therefore be too expensive for the aquaculture.

Extra equipment are more challenging to make, and they are always under development. What will come in the future is an extra equipment for removal of dead fish that can be mounted on the ROV. This will be equipment with functions for pump and suction.

4.10.4 ROVs instead of divers

Several service companies agree that ROVs have come to stay in the aquaculture industry and that they have a bigger potential than we see today. The development will probably take some time, as it is a constant focus on costs. The offshore industry are already using ROVs for more complex operations, so the possibilities are there, the challenge is to make them cheap enough for the aquaculture to use them.

Further technology development will probably allow ROVs to replace divers and implement tasks as drilling bolts, handling ropes, and sewing of holes in the future.

Most service companies and equipment producers agree that the industry most likely will need both divers and ROVs for a very long time, and that ROVs not will be able to replace a diver 100%. That is long into the future, but ROVs will for sure be able to replace some of the operations, which will be beneficial considering safety for the divers and efficiency of the operations.

Chapter 5

Discussion

This discussion chapter will first consider some limitations related to the data collection. Then it will continue to discuss topics relevant for the research objectives stated in chapter 1, section 1.3.1, page 4. The discussion will be based on the theory presented in chapter 2, and the results from chapter 4.

Note that the chapter will only discuss some of the relevant topics, as the result chapter is very comprehensive.

5.1 Data collection

Observations done through the three field works, interviews and conversations are creating the foundation for the discussion in this thesis. This information is related to how the different companies do things in practice, and what they think about the future trend of relocation into more exposed areas. Common for all companies are that the aquaculture industry is very busy, making it hard to reach people and find time for the interviews.

The chosen methodology is considered to be a well chosen one for the purpose of the thesis, as the thesis is providing an informative data collection. This chapter will discuss briefly some of the weaknesses that create small limitations that should be kept in mind when reading the results.

5.1.1 Observation through fieldwork

The thesis has chosen to focus on the three operations: Net inspection, mooring inspection and net cleaning. As indicated in the methodology chapter, section 3.3, page 40, a sufficient amount of observations would have been at least one observation of each of the chosen operations to get a visual aspect on how things work in practice. This thesis covers in total three observations, but only one that is highly relevant, and that is the mooring inspection. The lack of relevant observations creates a limitation when presenting detailed operational information.

As mentioned in section 3.3 page 40, observations are in general the best and most useful way of getting detailed information about operations in practice. Good weather is always an advantage when operating, because it minimizes the amount of challenges. Observations can confirm that, as the observed operations went very well. The operators seemed to be very relaxed and they could confirm that there where no major challenges on these days, except for some difficulties regarding visibility.

The observations were very informative, and the companies were very helpful answering all questions. That could be seen in the result chapter, chapter 4, section 4.5, page 66, as the gained knowledge about the operations are quite well covered, despite few observations. Since one of the objectives is to assess operational challenges, the good weather creates a small weakness in the observations. Literature and previous research mention that launch and recovery are a major challenge for ROV operations, but these are most likely to occur in bad weather because of the high waves. The workers can confirm that launch and recovery is challenging, but the observer were not able to observe how challenging, since the weather was too good. There were therefore no major challenges to observe, except from poor visibility here and there.

5.1.2 Interview guide

The conducted interviews are based on the interview guide that can be seen in appendix C, page C-1. A good interview guide requires the interviewer to have a certain understanding about the topic to be able to ask the right questions.

Some lack of sufficient background knowledge has lead to several modifications on the interview guide, which means that the guide is literally just a guide. This also creates a weakness in the quality of the interviews and the total data collection. It was to some extent hard to come up with good questions when asking about the *general safety management for ROVs*. There are also a few questions that just a few companies have been asked, because previous interviews and conversations made the interviewer more aware of different aspects. Despite a few modifications, companies have been very helpful, and the result covers a wide range of knowledge related to the objectives.

Another factor that should be kept in mind is that some companies did not have time for interviews as these took about one to two hours. Some interviews were therefore more like conversations, where the interviewer had to pick out the most important questions. Some interviews were also influenced by limited time at the end, resulting in some short answers on the latest questions. How the interviewer analysis the answers can also pose a weakness for the end product.

5.1.3 Contributing companies

Section 3.4.2 shows that the service companies providing ROV services here in Norway are highly represented as contributors, and also the equipment side is quite well covered due to the number of equipment producers in Norway. The fact that this thesis covers almost all relevant companies on the service and equipment side is an advantage and a strength when reading the results. Another advantage is that the companies are located at different sites, which means they do not necessarily operate on the same farms. That helps widen the range of the result, covering a larger area compared to only talking to companies working on the same type of sites.

It should be noted that the diving part is only covered by a few companies, which compared to service related information creates a verification weakness. Fish farm companies do also provide useful perspectives, but for this task only one company have been contributing. This creates lack of information from that perspective, but since the focus of the thesis is on ROV operations and not fish farm facilities, this has not been considered a very huge weakness.

5.1.4 Interview objects

When performing interviews, the results are depending on both the interview guide and the interview objects. As mentioned in section 5.1.2, the interviewer has the main responsibility of asking the right questions.

What is important to remember when a data collection is based on interviews, is that provided knowledge is highly related to what the interview objects are telling. It is important to remember that all companies do things their way, which means that what applies to service company one, not necessarily applies to service company two. Who the interview objects are, what they do, what they know, and what they can and want to tell will be crucial for the results. There are several companies with strict rules about what the employees are allowed to share when something is “official”. New developments and cost numbers are examples of information that not everyone wanted to give, due to the industrial competition.

When asking about operational procedures, risk and safety, there are a certain chance of getting subjective opinions rather than general ones. It is therefore important to keep in mind that some opinions in the result part only apply for some workers.

The final selection of interview objects is presented in table 3.4, page 46. There were no companies where just one person could answer all questions, in that case the informants were helpful in contacting the right people.

The selection underlying this thesis is therefore considered representative in view of the project’s objective of covering the ROV parts as most of the informants represent service companies or equipment producing companies. It must equally be taken into account that a larger selection would ass even more aspects that have not been included here. As will be mentioned in the section ”recommendations for the future”, section 6.2, page 104, several fish farmers will for instance be able to cover their point of view, which also will provide useful knowledge concerning the topic that are not that well covered in this thesis.

5.2 Divers vs. ROVs

Some of the main advantages and disadvantages with divers and ROVs are showed in table 5.1 and table 5.2 respectively.

Table 5.1: Advantages and disadvantages for divers

DIVER	
Advantages	**Disadvantages**
- Detailed and accurate work	- High level of risk
- Physical interaction allows for taking actions on the spot	- Limited physical protection that can cause health problems
- Frequent communication possibilities	- Depth limitation and diving time limitations

Table 5.2: Advantages and disadvantages for ROVs

ROV	
Advantages	**Disadvantages**
- No personnel under water	- Limited range because of the umbilical
- "Unlimited" power and high bandwith, because of the umbilical	- Exposed environment will create drag and other motion impacts on the umbilical
- Extra payload capacity	- Highly dependent on the experience and qualifications of the operator
- Less risk of human injuries and fatal accidents	- Hard to perform very accurate and detailed work
- The recent developed ROV motion control systems can provide quite high accuracy control	- Sensitive to environmental factors like waves, currents and other seabed conditions
	- Expensive operations

There are several advantages and disadvantages with both the diver and the ROV. Some disadvantages with a diver can be solved by using a ROV, and vice versa. Limited diving time for a diver can for instance be solved by using a ROV with unlimited power source.

While lack of detailed work from the ROV can be solved by using a diver. As seen from the tables, the main difference between a diver and a ROV is to what extent they can do detailed work, and how exposed the operators are during operation.

Sections 2.6.2 page 26 and 2.6.3 page 27 show that there are some specific regulations, but that companies can choose whether to follow them or not. Divers need to have a diving certificate, but there are no specific rules for the ROVs. After talking to the different service companies, it seems that they can decide which size and what type of equipment they want on the ROV.

5.3 Current IMR operations

The result chapter section 4.5 page 66 presents very well how current IMR operations are performed. Even though the observation part only covers the mooring inspection, service companies have been very helpful sharing knowledge related to the different operations.

When it comes to quality, all companies have a common comprehension that the quality of the operations are good enough today. They say they have what they need of equipment, and that if they miss something, they can usually get it within a short time. Even though they agree the operations are good enough, most of them doubt that they will be good enough when moving into more exposed areas. Key words such as better planning and more safety precautions are being mentioned.

5.3.1 Net inspection

According to the result parts the net inspection seems to be quite straight forward. Either the diver do this by following the net, checking it for deviations, or they launch the ROV, do the operation, and take it back up. They do also follow the given regulations by doing pre-dive and post-dive check of the ROV to make sure it is in a good operational condition. These checks are believed to be more important when the fish farms move into more exposed areas, because the harsh weather will most likely cause more wear and tear on the ROV and the extra equipment. Especially cables should be checked more frequently, as several companies mention these as a weak spot on the ROV.

Currently, fish farm companies choose whether they want divers or ROVs to do this operation. Some say divers take more time, but that it is more efficient if they actually find something wrong because the diver can fix the problem at once. A diver for instance, can only fix holes, and if these are discovered by a ROV, the ROV farmers need to wait for a diver to fix it. ROVs for net inspection is believed to be the most common procedure when moving into more exposed areas, due to safety for the diver. Divers will probably not be an alternative if the locations are very exposed. That will require the ROV development to come up with solutions that enables the ROV to repair nets. Some companies are mentioning the sewing machine produced by Sperre AS. After talking to several service companies, the concept of the sewing machine seems to be very good, and that the only problem is its size. It is a pity that no companies have really tried this out, as net repair is one of the operations that should be replaced by a ROV in the future.

The service companies says the fish farmers choose to use divers in case of holes, but when considering the frequency of how often deviations such as holes are discovered, it is very rare. Net inspection with ROV will therefore be more economically lucrative over time.

Equipment and stuff inside the cage have been mentioned as a problem for the ROV operations, because the ROV can get stuck. The unpredictable weather conditions in the more exposed areas will have stronger currents that will create more unpredictable movements in the water. This can be even more challenging, as the ROV is dependent on the hanging umbilical, linking the ROV to the surface vessel. More movement on the equipment in the ocean will also increase the risk of damaging the umbilical.

Another challenge with the net inspection is that it is time consuming, which indicates that if the same equipment and methods are to be used at the exposed areas, it will be even more time consuming. It was not asked for, but it sounded like most of the service companies only used one ROV at the time. They said it was because of the vessel size, and that it was only enough space to carry out one ROV at the time. One way to make the operation less time consuming is to use several ROVs at the same time. That will make the whole operation more efficient. The challenge here will be how to operate all the ROVs inside the cage without getting them tangled up in each other, meaning that the operation will be more demanding. As mentioned in the result part, the demand for skilled operators will increase as the operations are getting more challenging.

5.3.2 Mooring inspection

The mooring inspection seems to be quite straight forward, and the operation is usually conducted by a ROV. This is one of the operations where the use of a ROV for sure is the best option. Mooring lines are very often long, and the ends are often located in very deep water, where the uses of divers are not to be preferred. Using a diver for mooring inspection will be too time consuming, as the ROV can drive faster than a diver can swim. Also the depth is a limitation due to the given regulations for diving.

Divers are still required to fix any deviations that might occur. The challenge when moving into exposed areas is therefore how to fix the deviations that are located very deep. Divers can dive deeper with help from a saturation system, which is what the offshore industry uses. The main issue with that is cost, because application of saturation diving will be a lot more expensive compared to the diving operations today, because of more expensive equipment. Another suggestion will be to find a way for the ROV to fix the problem.

5.3.3 Net cleaning

The industry has already managed to develop specialized washing rigs that allow net cleaning to be implemented without having divers in the water. These washing rigs are based on the same principle as ROVs, and increases the safety of the divers. Challenging with these rigs are that they need to be launched by use of huge cranes. Exposed areas will increase the risk of the personnel handling these cranes, because stronger winds will cause unstable working platforms.

5.3.4 Other operations

Regulations related to ROVs state that if a ROV is going to observe a working diver, it must be keep at a certain distance, because if the ROV gets too close to the diver it can knock him out if the currents get too strong. Whether this regulation is followed or not is difficult to say. Based on the observation of the pipeline inspection it looked like the workers where aware of that, because there was mainly just one in the water at a time, either the diver or the ROV. Once they were done with the ROV they made sure it was safely placed on the vessel before the diver went out in the water. The fact that the company did this in relatively good weather, indicates that it is a common routine for those companies having both divers and ROV available.

5.4 How increased use of ROVs can make current IMR operations more safe and effective

The main reason for why increased use of ROVs should be considered at all is because it will mean less or no personnel under water that will increase the safety of the divers/workers. There are for sure diverse risks of operating above surface as well, but this thesis has focus on IMR operations under water, since that is where the ROV operates.

The data collection indicates that most people agree on how operations should be done, what should be in focus, and what challenges to take into account. For instance that weather is the major challenge when moving into more exposed areas, because the weather is an uncontrollable factor, and that ROVs and more automation is in the future.

When moving into more exposed areas, detailed panning of the operations will become an even more important routine. Service workers state that current operations are not necessarily planned for each time, as they are all the same, and "they know what to do". More challenging operational conditions may require the workers to plan their operations more frequently compared to today. Detailed planning will be crucial to maintain a safe operation.

Several sources can confirm that increased use of ROVs will improve the safety and the operation efficiency over time, as moving into more exposed areas give more difficult surface conditions. More autonomous functionality will both reduce the manual workload, and the human exposure, which will increase the safety of the operators. Important for the electronic components are that they have to be good enough to withstand the harsh weather, and to work in a salty water environment, which in general is really bad for them.

There is a mixed perception of whether automation and ROVs will be able to totally take over for the divers. A common perception is that it may be better to improve certain equipment on the ROV, and make these more autonomous, rather than aiming for fully automation. One thing that they all agree on is that making greater distance between operators and the operations will increase the safety of the workers. ROVs will therefore without a doubt create a safer working environment for the operators, and this section will try discuss some of the reasons why.

5.4.1 No personnel under water

As mentioned in the intro of previous section, less or no personnel under water is the main reason for why increased use of ROVs will increase the safety of the workers, and specially for the divers. Diving is always risky, because they are under water with a minimum of protection, and moving out into more exposed areas will only amplify the risk. Operations in the sheltered fjords are usually okay according to literature studies and service companies. The environment is quite predictable and there are no major challenges. Strong currents in the exposed areas will constitute great risks because of strong forces under the surface. It will make it harder for the diver to stay at place, and make him more exposed to unpredictable and fast movements of other objects in the water.

One current repair operation that exposes the divers the most are repair of nets. Currently these operations need to be done by a diver, although there are a few alternative existing solutions where ROVs are involved. The sewing machine produces by Sperre AS has already been mentioned.

5.4.2 More autonomous functions

More autonomous functions will not only increase the safety, but also increase the efficiency. Mooring and net inspections are two examples of that. These are very time consuming operations when using a diver compared to a ROV.

One mentioned on-going research project presented by Schjølberg and Utne (2015) state that there is still a huge gap before autonomy will be fully integrated in ROV operations, and that there are several challenges that need to be solved. One angle that has been mentioned before is to focus on making more additional equipment more autonomous instead of a fully autonomous vehicle. Making equipment more autonomous, or just a few functions more autonomous will also help increase the safety of the workers. This will also help dealing with several of the environmental challenges that will be considered in the next section.

More autonomous solutions might be able to solve the "umbilical-problem" in the future. The umbilical is vital for the ROV to function, but as the result part states, the umbilical is both practical and unpractical. Wireless ROVs can solve this problem, as it will give the ROV the freedom to move anywhere.

5.4.3 Help dealing with environmental challenges

Environmental challenges are here referred to as unpredictable weather changes, limited weather window, and extreme weather including high waves and strong currents. Some of the points that will be stated here have already been introduced when discussing the operations in section 5.3 on page 90.

Extreme weather

All companies agree that the environment is the major operational challenge. The difficult part about the weather is that is is unpredictable and uncontrollable, causing large movements in the sea that affects everything in it, in addition to a limited weather window for the operations. Strong currents will make it hard to keep the ROV still in the water, and are energy consuming for the diver. The high waves will as mentioned not really affect what happens in the water, but it will make operations such as launch and recovery for the ROV more challenging. Launch and recovery will not be considered in this thesis, as the focus area is on what is happening in the sea.

Limited weather window can easily cause stress and affect the operators to take wrong decisions that can give unfortunate consequences. Increased use of ROVs will not reduce the weather window, but it will decrease the risk of the operators if a situation goes wrong.

The ROV is operating very close to the net when doing the net inspection. Service workers say they have not touched or caused damages to the net yet, but that counts for the sheltered fjords. Harsher environmental conditions will increase the chances of damaging the net, while doing the net inspection. Dynamic positioning difficulties may cause the ROV to keep a larger distance from the net, which will give poor visibility if the distances get too long.

Depth, darkness and visibility

Currently, there are no specific problems with depth, but it might be a problem for the divers, as the cages get deeper. Deep water diving is in general nothing new, because they do it offshore, but it will require more equipment that will make the diving operation more expensive. ROVs are therefore one solution to minimize these costs.

Darkness influences the visibility, and several companies have mentioned this as a problem, especially during the winter season. The observations also made it clear that visibility also could be a problem at daylight. The ROVs will not necessarily solve the darkness and visibility issues, but they will for sure spare the divers of the risk operating under these conditions. Both ROVs that were used during the observations were equipped with a camera with limited zooming possibilities. Moving into more exposed areas might require some small updated for the equipment such as a better zoom function, which will allow the ROV to keep a safer distance to the net during inspections, without loosing the visible contact needed. One service company could also confirm that zooming abilities are something they miss.

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5.4.4 Human prerequisites

Divers need to have a diving licence, which is stated in the diving regulations. Service workers can also confirm that the certificate is needed.

The NORSOK standard states that workers should be familiar with electronics, automation, remote systems, hydraulics or electric. It is not clear how important the NORSOK standard is for the current aquaculture, but service companies can confirm that several of the workers have experience from the above mentioned fields of study. According to the service companies there are no specific requirements for the workers. The only requirement is that the workers know how to use the different systems. Since the NORSOK standard gives regulations for offshore operations, these are believed to be more important if and when fish farming relocates.

Required training

Most IMR operations will probably be implemented to the exposed facilities in more or less the same way as they are today in the sheltered fjords. The environmental challenges will for sure set higher standards for the ROV pilots, as they have to deal with more extreme and difficult operational environments. Literature study and interviews can confirm that moving into more exposed areas will increase the demand for skilled operators in the future. In section 4.7, page 77, service workers say that the main training happen through "learning by doing", which Sandberg et al. (2012) can confirm in their study as well.

What could be challenging with this "learning by doing" trend is that in the exposed areas, mistakes will have more critical consequences, as they could be a lot harder to fix within a sufficient time. As for a lot of other industries as well, "leaning by doing" is a normal way of teaching people how to react. Several companies that work offshore have moved this training onshore, by using simulations to create a virtual situation onshore that the workers need to solve. Having it in a simulation, creates room for mistakes without any real consequences. This thesis have not asked the companies if this is a solution, but it should be considered as a useful tool in the future, because simulation is the best way to make things as real as possible, but still controlled and safe. Setting up a simulation will cost money, but it will most likely be cost-effective over time. Simulation possibilities will also make room for trying out new ways of solving problems that might occur in the real life.

Specialized group

Section 2.7, page 28 presents that a recent trend for several service companies is to have specialized groups for different operations. This could be a clever solution when operations have to deal with more exposed areas, because specialization allows the workers to focus on one type of operation and how to implement this in the best way possible for both workers and the fish. One of the field trips could also verify this, as one of them had their own team for net cleaning. These were not the same people as they who drove the ROVs, which is why the result part lack detailed information on how this operation is completed. The company said this was necessary, because the washing equipment were different compared to the ROV, and that dividing into two separate groups were one way to assure great quality for both operations. Several companies confirm in result section 4.1 on page 48, that they also have their own washing teams.

Several workers believe that it is good that everyone in the company can rotate between operations, so that everyone know how to do the different operations that the company offer. This also makes it easy for them to replace each other if someone gets sick. This benefit will become more difficult with specialized groups. On the other hand, specialized groups may be the best solution towards better operational safety and efficiency.

Working hours

The industry is very hectic, and all service companies say that they usually work over time, which indicates that they may not follow the given regulations. This can also be confirmed during the observations, as two of the three field trips were delayed for different reasons. Still it seems like this is not a problem for the workers, as they all agree to the fact that most operations should be completed when they first are on site.

One of the operations was delayed due to an emergency situation, while the other one was because of some waiting due to poor logistic planning. Emergency situations are difficult to control, because they just appear, and they will maybe appear more frequent when moving into more exposed areas. One way to deal with the logistics is to better plan with other companies when to do the different operations. It did not seem like the operators cared about the delay, as they were very relaxed about it. Coordination with other companies are also somewhat difficult as it will always be some kind of collision, as every company have their own schedules.

If operations are getting more efficient that will make it easier for the workers to keep their scheduled working hours. Over time this will be better for them and result in less physical exhaustion, and reduce the risk of human errors due to lack of attention. Increased operational efficiency will also make it easier to keep the working hours within the given regulations.

Section 2.6 on page 23 states that there are given regulations for working hours, and that the working hours within the aquaculture follows the same rules as for normal land based work. The data collection may indicate, as already mentioned in this section, some flexibility around these as most of the companies work over time. All service companies say they work until they are done, and that it is okay for them as long as it does not happen all the time.

5.5 Other perspectives

5.5.1 Economical perspectives

Section 4.9 starting on page 79 states that one of the big question in the aquaculture industry is: "Economical costs vs. need". It is difficult to state any numbers, as the companies would not provide these because of competition in the market. Several of the numerical values in the result chapter are based solely on one source, and should therefore be considered as indicative.

Current situation is that ROV operations are considered cheaper to implement compared to diving operations, although the ROVs and the addition equipment are very expensive. ROV operations are also considered cheaper because they have unlimited diving time.

The contributing companies for this master thesis disagree on what is the main reason for choosing either divers or ROVs for the operation. Some companies believe the focus is to choose the cheapest operation method for the given purpose, while others say that fish farmers do not care about price as long as the quality is good and the company can deliver on a short response time. The advantage of short response time is that the problem is fixed quickly, which will minimize any negative consequences such as for instance fish escape.

It is believed that when moving into more exposed areas, quality and response time will be the crucial factors compared to price. By looking at the numbers provided in the result part, there are not really that big of a difference anyway.

5.5.2 Willingness to try out new solutions

Willingness to try out new solutions is vital for further development, and it is hard to actually state how willing the industry is. The end of section 2.5.3 on page 22 mentions one survey that found out that one challenge for the development is to find companies that are willing to test out the new solutions. The result part invalidates this statement, as several service companies say they are willing to try out new solutions.

Another study states that companies have become more willing to invest in better and safer solutions after NYTEK was implemented, see section 2.6 on page 23).

Several companies who contributed to this thesis say that they are more than willing to try out new solutions, but they do not hide the fact that is has to happen under controlled environments, because one mistake can cause them a seriously amount of money.

Independent of what the companies say, the bottom line is that willingnesss to tru out new solutions will continue to be crucial for further development.

5.6 Future needs

There are no doubts that ROVs will continue to take over several of the operations that are currently implemented by divers. Both the literature study and the interviews from this thesis can confirm that. This thesis also confirms that the development are on the right track, and that ROVs already have taken over some operations such as cleaning of nets and several inspections. To be able to continue this evolution, some aspects have come up throughout the thesis that will help satisfy the future needs.

5.6.1 Useful ROV improvements

Operations that require the ROV to be located quite close to the net will be challenging in harsh weather. Better positioning abilities will therefore be a useful improvement that will decrease the risk of damaging the net, and make the operation easier to implement safely for the fish.

As mentioned in section 4.1.2 on page 49, filming is very important for the customer to quality check the inspection. Good cameras are therefore crucial. It has been mentioned that better zooming abilities are desirable.

5.6.2 Stricter regulations

Several of the given regulations today are written specially for the offshore industry. After talking to the service workers it seems like most of them do not know about these, which is also logical as there are no specific regulations given for how to operate in the aquaculture industry today. It is not unlikely that these regulations will become stricter as the operations move towards more exposed areas, which can be linked to offshore areas.

5.6.3 Other needs

Section 2.7, page 28 indicates that cranes very often are too big for the service vessel, causing instability when operating in strong winds and high waves. This causes increased risk for the personnel and gives a clear indication that the vessels need upgrading if the are moving the industry into more exposed areas. Several service workers confirm this as a problem.

Current service interval for a ROV is twice a year. This will probably become more frequent as the exposed areas will lead to more wear and tear on the ROV under operation. Regular maintenance will in general be more important.

Chapter 6

Concluding Remarks

This chapter is the rounding off of the master thesis. It presents the main conclusions based on the objectives stated in the introduction. There are also some recommendations for further work presented at the end.

6.1 Conclusion

The main topic of the master thesis has been to analyze current situation around ROV operations in the have focused on three research objectives:

- Expand and further develop knowledge about current diving and ROV operations in aquaculture, focusing on when, why, how, and challenges.
- Assess the expected frequency of ROV operations in future exposed fish farming, as a basis for feasibility studies of, for example, different launch and recovery solutions.
- Gather information about operational costs for diving and ROV operations and discuss whether increased use of ROVs are beneficial or not due to safety, improved operational efficiency and cost savings.

Data has been collected through observations, interviews and conversations with different stakeholders, which has resulted in a detailed overview of the three main operations net inspection, mooring inspection, and net cleaning. Most companies agree that the quality of these operations are ok as they are now, but that they may not be good enough when moving into more exposed areas. There are some requirements for the minimum number of required operations within a given period of time, but there are in general no fixed routines. The fish farmers are responsible for contacting the service companies whenever they are needed and as frequent as necessary.

The major challenge for both diving and ROV operations are the weather. The weather is causing several challenges that are strongly believed to be even more difficult in the more exposed areas. Divers may not be able to operate on all exposed locations, which indicates a higher frequency of ROV operations.

Current technology development will make ROV operations safer and more efficient compared to diving. Still, the ROV technology has a long way to go until a ROV can fully take over for a diver, but researches and developers believe that with some more automation they will be able to do a lot more than today.

An overall conclusion is that ROVs will increase the safety of human operators, and the operational efficiency. The safety will increase because use of ROVs indicate less diving operations, and less human interactions. While the efficiency will increase as the technology will make the ROVs operate quicker in the future.

6.2 Recommendations for further work

The best recommendation for further work is to personally meet with the companies, and to be active on the phone. The industry is hectic, and appointments arranged over the phone are easily forgotten. Use the phone to check and make sure the companies remember the appointments.

Section 5.1.1 page 86 mentions that the thesis lack a sufficient basis when it comes to mapping through observation. Further work on this topic should therefore consider doing more observations, and if possible, do them when the weather is not that good. Too good weather will as the thesis have stated, not necessarily give something special to observe.

To really cover all the involved participants, an expansion in the range of contacted companies should be considered, and especially within the fish farming companies. Several fish farm companies should be contacted to better cover their point of view the on current situation. As the result part indicates, these companies may not be that much involved in the operations, but they still provide useful and interesting perspectives and inputs to the relocation question. The diving part could also be better covered by contacting more diving companies.

An interesting aspect to further expand the topic of the mapping of ROV operations is to contact companies which provide offshore operations. Current offshore solutions could as mentioned in section 2.8 page 32 not be used directly in the aquaculture without modifications, and talking to offshore companies can therefore give valuable inputs on what kind of modifications are required. This will also provide a wider understanding of what to expect when moving into more exposed areas.

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Appendix A

Task description

This appendix provides version 3 of the task description that was stated in the very beginning of the master work in February 2017. The master thesis was intended to be a continuation of the project thesis, so the very first master thesis proposal was already made before starting on the project. Since that, the thesis description have been through some changes.

VERSION	DATE	MODIFICATION
1	August 2016	The very first task description that was given at the same time as the project thesis, with the intended project thesis as basis.
2	September 2016	Modifications were made to better fit the interests of the master candidate.
3	February 2017	Some of the objectives were changed based on what was done in the project thesis.
4	July 2014	The title has been changed. Otherwise there are no major changes from the one presented here. The final task description is provided in the introduction of the thesis, with all related objectives and limitations etc.

NTNU
Faculty of Engineering Science
and Technology
Department of Marine Technology

MASTER THESIS IN MARINE UNDERWATER TECHNOLOGY

Summer 2017
For
STUD.TECH. Anne Jieli Louise Solem

Analysis of ROV operations in aquaculture
- Reducing risk in exposed aquaculture operations

Background

Current technologies and operations in fish farms are highly dependent on manual labour for cleaning and maintenance, which leads to close human interactions with tools and fish cage structures. The sea-based aquaculture industry is one of the most dangerous occupations in Norway, and fish farms operate at the edge of safety limits. Moving fish farms into more exposed areas will lead to increased challenges related to the working environment and management of operations, due to more severe weather conditions, remote locations, and demanding sea states.

Manual labour and operator interactions with the cage structures and on going processes are still needed, but it is necessary to make the processes less dependent on manual intervention, and develop more autonomous technology with different levels of self-governance and self-control. Currently, removal of dead fish, and other inspection, maintenance, and repair (IMR) operations are typical manual operations performed for each fish cage. ROV or divers are used for inspections and repair of the cage structures and mooring system. Net cleaning is done with high pressure cleaning rigs and cranes, which are operated by humans situated on board service vessels. Increased autonomy in such operations could, for example, lead to fewer diving operations and less people present at the sea facilities, thereby reducing risk.

Typical underwater maintenance and repair tasks in aquaculture are cleaning of nets, repair of the nets, mounting of ropes, removal of dead fish, inspection of cables and anchoring operations of the cages. Cleaning of nets is performed by ROVs using specialized cleaning rigs, and inspection of cables and anchoring are performed by ROVs from service vessels. Hence, either divers and/or personnel on the cages perform the other operations.

Scope of Work

This master thesis is a continuation of the work done by the same candidate in her project thesis that was completed under the subject code TMR4550, during the 2016 fall semester.

The overall objective of this master thesis is mapping of current ROV operations in aquaculture with respect to operational requirements, procedures and documentation. Investigate the potential for risk mitigation for operators by increased use of ROVs, by considering whether ROVs creates better or worse solutions by assessing strengths, weaknesses, challenges and costs compared with divers. The work aims to identify for which operations divers are required, how often diving is performed, and their operational limits and constraints. Further, the thesis should identify potential for increased use of ROVs and necessary improvements.

This means that the thesis should help mapping the gap between the performance and capabilities of divers and the current and future performance of (autonomous) ROVs. Such a gap analysis may provide important input to prioritization and future research and developments in ROV technology, including launching and recovery systems of ROVs. Also, it may be used as a basis for an extended autonomous job analysis (AJA), for example related to the use of ROVs inside or outside cages for revealing of holes in the nets, and the need for risk reduction measures.

The following objectives are to be completed:

- Interview stakeholders to expand and further develop knowledge about diving and ROV operations in aquaculture, focusing on when, why, how, and challenges.
- Assess the expected frequency of ROV operations in future exposed fish farming, as a basis for feasibility studies of, for example different launch and recovery solutions.
- Gather information about operational costs for diving and ROV operations and discuss whether increased use of ROVs are beneficial or not, due to safety, improved operational efficiency and cost savings.

Start date: February 6th, 2017 **Due date:** July 24th, 2017

Main supervisor: Ingrid Bouwer Utne

Appendix B

Fieldwork

This appendix presents the field trips to the fish farm company and also one of the service company.

B.1 Fish farm company

The first field trip was to a fish farm company, who runs two facilities:

- Facility one is a steel construction with less capacity than facility two that is a ring construction. The cages are designed as 8x2 connected squares, which makes it less space demanding. Steel constructions are more sensitive to movements, which is why this facility is located into a more sheltered location than facility two. The design is also older.

- Facility two consists of eight ring cages. These have a diameter between 120-150 meters, and are not connected to each other. They can contain up to 200 000 fish, and the facilities are quite new and modern. It has not yet been completed a delousing process, but this will be done later if necessary by a fish carrier.

Both facilities use cameras in the sea cages for observation purposes, and also for some inspections. In general they do not use any divers, only ROVs for observation. When divers are required, they are usually required at facility one.

The observation lasted for one full day, starting with a morning meeting at 7:00 AM, before driving out to facility one. Today they were five employees present, usually they are seven. It is common to have a morning meeting every morning. After the meeting, the employees are divided into two groups where each group take one facility each. They usually do not have any common meeting at the end of the day. The morning meeting is therefore useful so that everyone gets an update on what was done the day before, and what needs to be done during the day. Observes that the morning meeting is characterized by a good, controlled and calm atmosphere in the group.

The plan was to stay at the steel facility due to the group dividing, but for the occasion, the ring facility was visited as well. This was very useful, giving a huge learning outcome. Being able to see the different between the cage designs made it easier to understand possible challenges due to different operations. The weather this day was in general very good, and the workers had very little to do except from the daily routines as general observation through cameras in the cages, feed monitoring, and dead fish removal. The purpose of general observation is to make sure the fish condition in the cage is good enough. Cameras are moved up and down in the cage and also one employee are observing from above surface. Physically observation is also done for observing when the food is released.

Other routines are counting of sea lice and changing of seine. Counting of sea lice is done manually by taking up approximately 20 fish and check them, how often depends. Changing of net is done every 2nd week between April and October, after that every 3rd week due to less algae growth.

Daily maintenance involve cage inspection, and feed monitoring through cameras and physical observation. Physical observation of feeding is done by throwing out some feed and directly observe the appetite. Weather is not really a limiting factor, because feeding is regulated from the inside. Removal of dead fish should be done every other day. Facility one does this manually by pulling up the landing net, and remove the dead fish using a hand net. Facility two uses the *LiftUp* system for this, which very brief is an equipment pumping fish from the landing net and up to the surface. This method is very effective, but it kills an undesirable large amounts of wrasse. A fish farm only gets a certain amount of wrasse. Too much loss is therefore very undesirable.

The good weather this day made the working day quite relaxing. The sun was shining and it was quite calm air. Everything went well, and the workers were able to do everything on their schedule. They were able to end the day at scheduled time, around 5:00 PM.

B.2 Service company - Pipeline inspection

The second field trip was to a service company, were a pipeline inspection was scheduled for the day. The service company had already been informed about a leakage on the pipeline. The inspection itself is not very relevant for this master thesis due to the chosen IMR operations, and the fact that pipeline inspection has nothing to do with a fish farm. Still, this field trip was considered important to be able to observe the interaction between usage of a diver and a ROV.

A pipeline inspection is not necessarily a high prioritized task, and a rush job made the operation around 3-4 hours delayed. The company used a relatively small boat that could only drive 20 knots. The boat was equipped with diving equipment and a slightly small ROV with a simple arm, as well as a small crane for launch and recovery. The crew consisted of two service me from the service company, two extra divers meeting up at the same place as me, in addition to two represents from the customer company. The pipeline is located close to the shore, with just some minutes of travelling time.

The operation started with the customer informing the service company about the leakage, and also showing were they though it might be. As a first step, they launch the ROV and use that for observation. Since the pipeline was laying relative close to land, it was difficult to find it because of brackish water causing poor visibility. The pipeline was also heavily buried. After several minutes of trying to locate the pipeline with the ROV, they gave up and decided to send down a diver instead. The diver prepared while the ROV was taken up. The boat was so small that the diver could jump from the rail. Before the diver was jumping into the water, another diver assisted him and helped him check that everything was okay. That the air intake and communication equipment were working correctly.

Constant monitoring of breathing frequency is one way to control weather the diver is in trouble or not. While the diver was in the water, one person was always communication with the diver, and another one to the person outside on deck. The diver was guided by the people on the boat, and it only took him a few minutes to locate the pipeline. Then he tried to find the leakage. After just a few minutes, the operational manager told the diver to come back again. He wanted to use the ROV again, now that they knew were the pipeline was. The diver came up, and the ROV was launched again. The ROV followed the pipeline along the seabed until it found the leakage, which could be seen as small bubbles. Due to no huge improvements on visibility, the diver was sent back to inspect the damage and the ROV taken up again. After inspection they used some minutes to discuss what to do, while the diver was still in the water. Normally such a damage would have been fixed on site, but due to lack of required equipment, they had to just leave the problem. The damaged area was marked with a buoy, and the operation ended with the intention of coming back the next day.

The weather was good this day, but the operational manager said it was challenging to keep the ROV steady in the water because of rough currents. He was also a little bit worried about damaging the pipeline, because it was so small. The working environment was very calm and controlled. It seemed like everyone knew what to do, and they were all very polite to each other. Everyone participated when discussing what to do around different situations as when to use the diver when the visibility became too bad, and what to do when the leakage was inspected. They all agreed that they could not fix the problem today, and the conclusion was made quite quickly.

Appendix C

Interview Guide

This appendix provides the interview guide used for the data collection.

Goal:

Map current ROV operations within aquaculture with regard to operational requirements, routines and documentation. Discuss to what extend ROVs create better solutions by assessing strengths, weaknesses, challenges, and costs compared to divers. Identify what improvement potential should be in focus for the future.

Today's aquaculture

- Interest around today's aquaculture industry
- Much new?
- Increasing needs?

Exposed areas

- Definition, common term, regulations
- General challenges
- Need for this development?

Normal working day

- How is a normal working day? Is it the same every day, every week, every month?
- Is it hectic? Easy to set time for this interview?
- Documentation during normal operation. What and how?
  - Checklists, diaries - data or paper?
- Supporting materials today. Have there been any changes over the years?
- Routines, equipment or anything that makes the work day more bothersome?
  - Has this been better or worse over the years?

Divers

- Working days, diving time, use of time and time limits.
  - Can they work till they are done?
- Laws and regulations
  - Related to divers
  - Diving on exposed areas?
- The diving industry's reputation

Diving operations

- Operational requirements in accordance with regulations
- Execution of operations
  - Pros and cons?
- Time perspective and time window for general implementation
  - Crucial factors
- How often are the operations performed? Satisfactory?
  - What can possibly be done to make it more satisfying?
- Weaknesses and challenges
  - Relative to weather
  - Relative to fish farm designs (rings vs. steel)
  - Safety perspectives
- Quality of operations, are they good enough today?

  - Improvement potential
  - Are there any better solutions today that are not in use? What and why are they not used?

- Work routines and division of labor
- Communication flow during operation
- Necessary and satisfactory equipment
  - Could they have been better designed?
- Rules for necessary equipment?
- What kind of aberrations do you look for, how often do you find them, and what is the cause?
- How quickly are aberrations / problems resolved and how?
- Benefits compared to ROVs
- Diving accidents
  - Background
  - How often do they happen?

ROVs

(Everything here and down is only about ROVs)

- Uptime for ROVs, how often do they fail and when should they be replaced?
  - Which parts of the ROV are most vulnerable and easiest to fail?
    * Can and should these be improved?
  - Which parts usually fail, and are the consequences critical?
- Routines for use and handling of ROVs
  - What happens if something becomes defective? Do you have extra parts ready or put everything on hold? In that case, for how long?
  - How defective can a ROV be before it can not be used for further operation?
- Routines for maintenance

ROV operations in general

- Planning and routines

  - Do most operations go as planned?
  - Planned in advance versus ”autopilot”?
  - What is the emphasis on during the planning phase?

- Required data collection before operation
- Documentation of operation
  - Risk assessment before, during and after?

ROV operations in practice

Main focus on three operations: Seine inspection, mooring inspection, and seine washing and net cleaning. Also remember to ask for other common ROV operations.

- Operational requirements in accordance with regulations
- Execution of operation
  - Advantages and disadvantages
- Time perspective and time window for implementation
- How often are the operations performed? Satisfactory?
- Weaknesses and challenges
  - Related to weather
  - Related to fish farm design (rings versus steel)
- Are the quality of the operation good enough today?
  - Improvement potential
  - Are there any better solutions today that are not in use? What and why are they not used?
- Work routines and division of labour
- Necessary and satisfactory equipment. Could they be better designed?
- Rules for necessary equipment?
- What kind of deviation do you look for, how often do you find them, and what are the causes?
- How quickly are any deviations / problems resolved and how?
- Benefits compared to divers

Critical ROV operations

- Which operations and why?
- Precautions
- Necessary operational improvements

Decisions / Responsibilities

- Procedures in case of interruptions
  - Documentation
  - Distribution of responsibilities
- Communication flow to shore
- Check of operations

General safety management for ROVs

- Requirements given by the government relative to safety management, procedures, risk assessments, supervision, preparedness plans, technology etc..
- How are the requirements implemented in practice, and are they being followed?
- Experiences due to the requirements
- Are there any procedures that can not be followed in practice? Which, and why?
- Suggestions for changes today

Training and follow-up

- Training and certification requirements for employees
  - Can everybody drive ROV?
- How does the training take place in practice? Courses, web courses, seminars..

Collaboration with other work teams

- Execution of operations
  - Coordination, cooperation and division of responsibility
- Does the cooperation make the operations easier, or more difficult with regard to implementation, cooperation and time pressure?
- Improvement suggestions

Cost and needs

- Cost of diving operations
- Cost of ROV operations and associated equipment
- Is the cost a deciding factor in choosing divers or ROVs?
  - Limiting factor?
- Need for both divers and ROVs?
- Is the industry willing to invest in better ROV solutions?
  - Why, or why not?

The future

- Concrete goals for fish farming
- Concrete goals for related equipment
- Will the ROVs take over for all divers?

Appendix D

Reporting systems for documentation

Documentation before, during and after operations are very important, regardless of company type (fish farming or service). Companies are free to choose whatever system they prefer for documentation purposes. This appendix presents the reporting systems that the companies say they use.

D.1 Extend Quality System (EQS)

Extend AS is the owner and developer of the EQS software. They write on their web page that this system can be used by all types of businesses, and that it is a comprehensive solution for quality and business management. It is a tool helping to organize the documents in the organization, and it consists of a number of different modules. The modules can either be used individually or in cooperation with each other. This quality system contributes to better overview, increased productivity and efficiency, reduced costs, better quality and safety, and more satisfied employees and customers. The system is flexible and can be used online, which makes the availability quite satisfying (Extend, 2017).

D.2 Infront-X

The intention of Infront-X is to provide their customers with a "Horizon experience". The mission is to assist the customer to be the most well-managed and profitable company within the aquaculture industry. Infront-X can provide a total of six different products:

1. Horizon Management Tool (HMT)
2. Horizon Optimizer (HO)
3. Horizon Planner (HP)
4. Horizon Budget (HB)
5. Horizon Equipment (HEQ)
6. Horizon Reports Studio (HRS)

Each of the products have their own intentions and focus areas, and the names are quite self-explanatory. It is not considered relevant for this master thesis to explain each of the products. What is necessary to know is that all products together covers a wide range of what is needed in the aquaculture industry (Infront-X, 2017).

D.3 NAVIAQ

Naviaq is a logging system tailored to the aquaculture industry, owned by Norsk Navigasjon Holding AS. It is a tool for effective interaction between breeders and service providers, that gives them both full overview of which service vessels carry out which jobs. Once the job has been completed, the invoice database can import directly to the financial system, making it easier to access the bill. It can also easily be used to send and receive changes inwards (Naviaq, 2015).

Naviaq is meant as a help to lift the farming industry to new heights by introducing new industry-focused Information and Communication Technology (ICT) solutions based on proven technology from other industries. It works well both offline and online, which allows service boats to document their work wherever they are (Naviaq, 2015).

Naviaq cooperates with AQS AS, Lerøy Midt and Hepsø Norservice. AQS AS states that Naviaq is very user-friendly and well arranged, and that it helps them increase the efficiency of their work. Naviaq also provides total control over the facility for the farmers, because whatever AQS AS reports goes directly to the fish farmer (Nodland, 2016).