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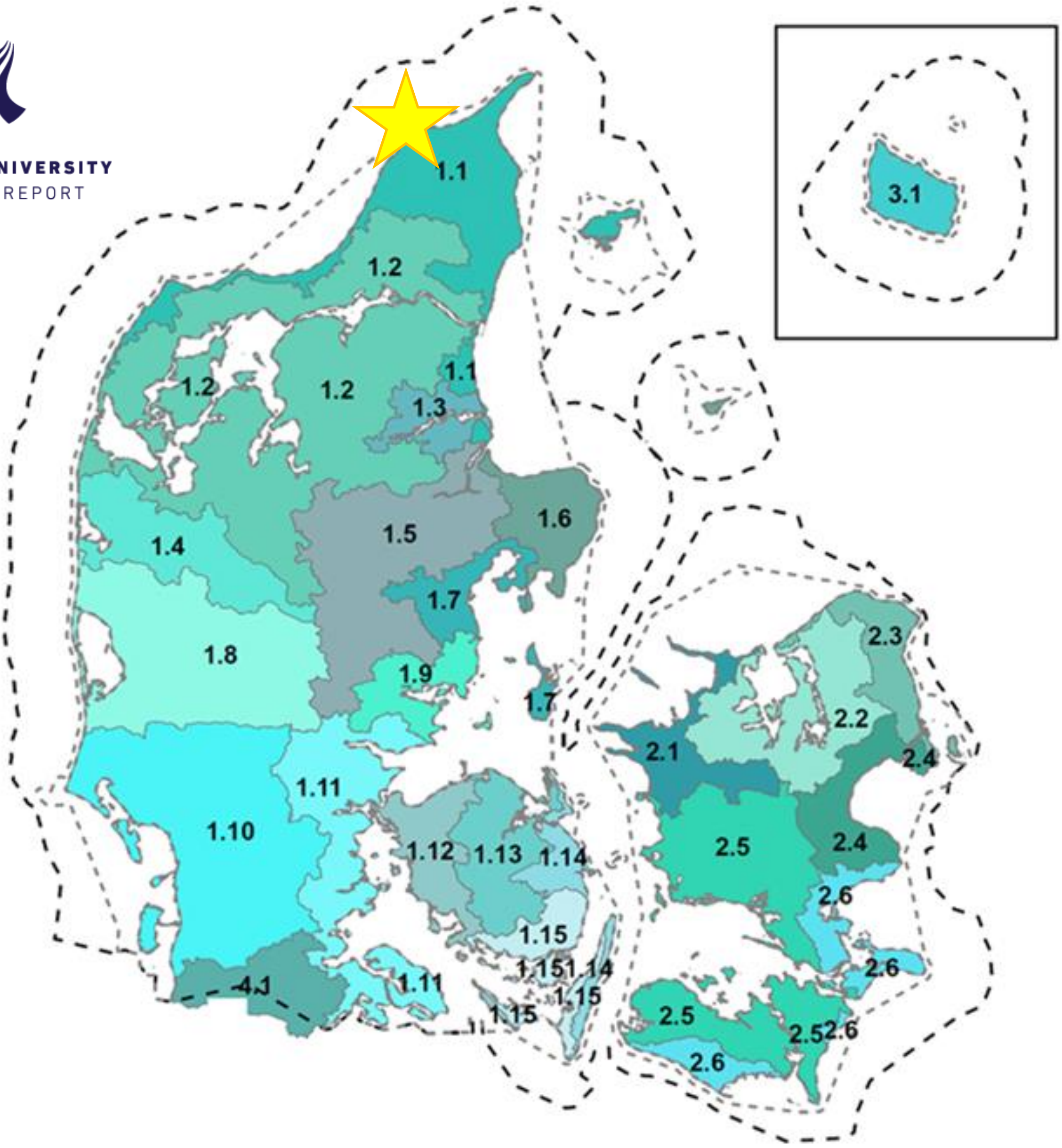


# SUSTAINABLE MANAGEMENT OF WATER IN CLOSED LAND-BASED AQUACULTURE SYSTEMS

## The Case of Danish Salmon in Nordlige Kattegat, Skagerrak Catchment Area

Dominique Smith-Hart

2nd June 2017

Environmental Management
& Sustainability Science

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The Case of Danish Salmon in
Nordlige Kattegat, Skagerrak Catchment Area

MASTER THESIS

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& SUSTAINABILITY SCIENCE

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# Abstract

Fish farming on land poses a positive solution for the increasing population and demand for healthy food sources as oceans are overfished. However, what are the consequences of this regarding water quality and waste management? This study explores how the water and waste framework directives have been implemented in Denmark for closed land-based aquaculture fish farms and addresses the problem statement: ***How is waste and water managed sustainably in closed land-based recirculating aquaculture systems in relation to the Water Framework Directive and other legislations?*** Qualitative data from literature and interviews were used. Documents from the Danish Environmental Protection Agency, Food, Agriculture & Health Organisation, DHI and Hjørring Municipality were used for information and analysis. A face-to-face interview with Hjørring Municipality and a telephone interview with AKVA Group were carried out to discuss and discover elements of water quality and waste management problems from environmental permits and technology perspectives, respectively. Issues with access to information were also addressed and how to overcome this. To discover the challenges of implementation of the water framework directive in closed land-based aquaculture, the circular economy and sustainability challenges were used as a conceptual framework. This also helped address what must be set up to remediate the current management of water in these reuse systems. A case of a functioning fish farm, Danish Salmon (Hirtshals) was analysed through best available technology, an environmental impact assessment and environmental discharge permit to find problems and create solutions. A focus on the water quality and nutrient waste were main aspects into the environmental sustainability of waste management within the farm. The conclusions of the analysis were that land-based aquaculture is a positive sustainable solution to food demand with increasing populations, but with gaps for improvement regarding waste management; the need for Municipalities to communicate better with information on discharge levels with access to information to be sourced easily and justification for these levels. Specific certification for land-based fish farms are required, building on the existing certifications. Similarly, waste management procedures could be used in other areas of agriculture. Future work could include biomimicry as a method of waste management; discourse in the legislation and between those who suggest recommended guidance, also between fish farmers, associations/organisations and academics.

**Keywords**: Circular economy; Land-based aquaculture; Recirculating aquaculture systems; Reuse; Sustainability; Waste management; Water Framework Directive; Water quality.

# Preface

This document presents the Master Thesis ***"Sustainable Management of Water in Closed Land Based Aquaculture Systems – The Case of Danish Salmon."***

This Master Thesis is the 4th semester of the Master's Programme in Environmental Management & Sustainability Science (EMSS) at the Department of Development & Planning, Aalborg University.

The thesis project was undertaken during the period 1st February to 2nd June 2017.

The project supervisor is Henrik Riisgaard, Teaching Associate Professor & Programme Co-ordinator of the Masters in Environmental Management & Sustainability Science.

All material used has either been written in English or Danish. Materials written in Danish have been translated in to English using Google Translate or via native Danes.

My interest in the topic and purpose of this thesis report stem from my internship during the previous semester where I began researching land-based aquaculture and the recent growing technology of recirculation aquaculture systems. I am also interested in water and the need to conserve this precious resource and use it wisely. With fish from oceans being overfished and the scare of toxins running in the food chain i.e. micro-plastics, an alternative option is required to produce healthy food available to everyone. Moreover, the topic is very interesting to explore and discover how sustainable land-based fish farming is in terms of water and waste management, how it is achieved and how it can be improved.

A focus on Denmark was a conscious choice as I would like to extend my stay after studying and work here, possibly in the aquaculture industry where I would like to further learn, help and assist with the future of land-based fish farming.

**Reading Guideline**

The report is divided into numerated chapters. Each main chapter includes an introduction outlining the content. The report uses the APA (sixth edition) referencing system using the Microsoft Word Referencing.

**Acknowledgements**

I would like to extend my gratitude and thanks to Nethe Ottesen at Hjørring Kommune for her warm welcome, time and knowledge in to recirculating aquaculture systems and the process of being environmentally approved. Also, for the additional sources of information and recommendations.

Many thanks to Jacob Bregnballe from AKVA Group for allowing me to interview him one evening sharing his input and assistance in fish farming on land and the technology associated.

Also, to those who spent time communicating through email and answering questions, providing information and further sources to help explore this topic.

Finally, to my supervisor, Henrik, for your guidance and support throughout the semester and your interest in this exploratory topic.

***Front cover image**: Subdivision of Denmark in 4 river basin districts and 23 river basins/water catchment areas, with a star showing the location of the case study, Danish Salmon in Nordlige Kattegat, Skagerrak catchment area. Source: Vandområdeplan 2015-2012 for Vandområdedistrikt Jylland og Fyn, Page 9 (Miljø- og Fødevareministeriet Styrelsen for Vand- og Naturforvaltning, 2016).*

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## List of Abbreviations

| | |
|---|---|
| **ACFA** | Advisory Committee on Fisheries and Aquaculture |
| **ASC** | Aquaculture Stewardship Council |
| **BREF** | Best Available Techniques Reference Document |
| **DEPA** | Danish Environmental Protection Agency |
| **EIA** | Environmental Impact Assessment |
| **EMF** | Ellen MacArthur Foundation |
| **FREA** | Fully REcirculated Aquaculture system |
| **LBAF** | Land-Based Aquaculture Farm |
| **LIS** | Library & Information Science |
| **IDH** | Dutch Sustainable Trade Initiative |
| **IWRM** | Integrated Water Resource Management |
| **MST** | Miljøstyrelsen |
| **N** | Nitrogen |
| **NKSCA** | Nordlige Kattegat, Skagerrak Catchment Area |
| **P** | Phosphorus |
| **RAS** | Recirculating Aquaculture Systems |
| **RBMP** | River Basin Management Plan |
| **SVANA** | Agency for Water & Nature Management |
| **WFD** | Water Framework Directive |
| **WWF** | World Wild Fund for Nature |

# Glossary

This glossary is for highlighting Danish words and names of organisations which have been translated to English for the purpose of this report.

| | |
|---|---|
| **Bekendtgørelse** | Executive Order |
| **Dansk Akvakultur** | Association of Danish Aquaculture |
| **Godkendelsebekendtgørelsen** | Approval Statuary Order |
| **Kommune** | Municipality |
| **Landbrugs- og Fiskeristyrelsen** | Agriculture & Fisheries Agency |
| **Miljøbeskyttelsesloven** | Environmental Protection Act |
| **Miljøgodkendelse** | Environmental approval |
| **Miljø- og Fødevareministeriet** | Ministry of Environment & Food |
| **Miljøstyrelsen (MST)** | The Danish Environmental Protection Agency (EPA) |
| **Miljøtilsyn** | Environmental Supervision |
| **Miljøtilsynsbekendtgørelsen** | Environmental Protection Order |
| **Naturstyrelsen** | Danish Nature Agency |
| **Styrelsen for Vand- og Naturforvaltning (SVANA)** | Agency for Water & Nature Management |
| Vurdering af Virkninger på Miljøet **(VVM)** | Environmental Impact Assessment (EIA) |
| **Vandområdeplan** | River Basin Management Plan (RBMP) |

# 1. Introduction & Problem Formulation

*The Master thesis will describe the waste management of closed land-based aquaculture systems and the treatment of water in a sustainable context, investigating EU directives and multi-level governance perspectives. An overview of the current regulations and technologies is a focus point as it will highlight existing problems and as such, allow for suggestions towards sustainable solutions that could be implemented and emphasised.*

Due to a growing population, there are more mouths to feed and thus the demand for food increases. One area struggling with this demand is the ocean, used for fishing. Currently, the act of fishing in the ocean has a trend of unsustainable overfishing and thus giving aquaculture a bad reputation. Additionally, there is a scarcity of available fresh water in the world which must be managed critically and carefully. Certain industries use copious amounts of water which could be reused and recycled. These two issues open an area of which fish farming can be achieved on land with a limited amount of water.

> *"70% of all water used globally goes into farming and the processing of food. This is an important advantage of aquaculture – producing a kilo of beef requires 15 cubic metres of water, whereas sustainability farmed fish takes only a fraction of this amount"*
>
> *– Jesper Heldbo, Secretary General, Ph.D. AquaCircle[1], Centre for Knowledge Sharing on RAS ( Rethink Water network in Denmark, 2017).*

The following table shows a comparison of animal protein production in terms of edible meat, carbon footprint and water retention:

| | COW | PIG | CHICKEN | FISH |
|---|---|---|---|---|
| **EDIBLE MEAT** PER 100KG FED | 4-10Kg | 17Kg | 21Kg | 61Kg |
| **CARBON FOOTPRINT** KG CO2 / KG EDIBLE MEAT | 30Kg | 5.9Kg | 2.7Kg | 2.9Kg |
| **WATER RETENTION** LITRE / KG EDIBLE MEAT | 16,400 litre | 6,000 litre | 4,300 litre | 2,000 litre |

*Table 1 Shows the comparative figures of animal production and how the production of fish has much lower values than cattle (cow, chicken and pig), showing a positive food source with low environmental impact in terms of sustainability. The total water footprint data are based on farmed salmonid fillets in Scotland, in relation to weight and content of calories, protein and fat. Source: AquaCircle PowerPoint presentation (Heldbo J. , Short introduction to Denmark and prospects of Danish aquaculture, 2015) & Marine Harvest Salmon Industry Handbook 2016 (Marine Harvest, 2016).*

[1] AquaCircle are a Business Membership Organisation focussed on recirculatory aquaculture and the continuing research and development of knowledge and technologies.

Fish is highlighted in the table as it is the most sustainable animal production for human consumption in terms of amount of edible meat compare with carbon footprint and water retention. This table shows the positive outlook of producing fish on land which also requires less land than the other animals.

The industry of aquaculture is increasingly growing due to the increased demand in food as the world's population rises. Additionally, the availability of clean water is limited and creates water shortages in certain areas of the world. Current farming of fish, achieved in a traditional fashion, poses a threat to human health, fish welfare and the environment. To improve this, this master thesis researches the possibility of a clean and sustainable alternative by investigating the treatment of water and waste in closed land-based recirculatory systems and the uses of this waste as a resource, as well as the reuse of water.

Land-based aquaculture covers all farming of fish, plants and crustaceans produced and harvested on land. It includes ponds, raceways and closed farms. This thesis will focus on closed land-based aquaculture farms using recirculatory systems. Currently, there is approximately 14-17 closed recirculatory aquaculture system (RAS) / fully recirculated aquaculture system (FREA) facilities in Denmark:

| *Type of fish farm* | Amount |
|---|---|
| *Eel* | 5-7 |
| *Salmon* | 5 |
| *Kingfish* | 1 |
| *Rainbow trout* | 1 |
| *Pike perch* | 2-3 |

*Table 2 Shows the type and amount of closed land-based aquaculture facilities using recirculatory systems in Denmark. Information taken from an email with Larsen from the Danish Environmental Protection Agency (EPA) (Larsen, 2017).*

With increasing research into technology and improvements in their functioning, recirculatory systems show a significant difference in water consumption and degree of recirculation the more intensive the system is. This is showed in the below table taken from the *"A Guide to Recirculation Aquaculture"* (Bregnballe, 2015).

| Type of System | Consumption of new water | | | Degree of recirculation at system volume recycled one time per hour |
|---|---|---|---|---|
| | per kg fish produced per year | per cubic meter per hour | per day of total system water volume | |
| **Flow-through** | 30 $m^3$ | 1,712 $m^3/h$ | 1,028 % | 0 % |
| **RAS low level** | 3 $m^3$ | 171 $m^3/h$ | 103 % | 95.9% |
| **RAS intensive** | 1 $m^3$ | 57 $m^3/h$ | 34 % | 98.6% |
| **RAS super intensive** | 0.3 $m^3$ | 17 $m^3/h$ | 6 % | 99.6% |

*Table 3 Comparison of a flow-through system and different RAS intensities in terms of consumption of new water and degree of recirculation. The calculations are based on a theoretical example of a 500 tonnes/year system with a total water volume of 4 000 $m^3$, where 3 000 m3 is fish tank volume." Taken from "A Guide to Recirculation Aquaculture" published by the FAO & Eurofish International Organisation (Bregnballe, 2015).*

There are many policies for the management of water, where integration is the only way forward for sustainable water to be achieved. Additionally, if Danish aquaculture is to grow sustainably, the management of nitrogen is a necessity that must be achieved to decrease levels of discharge. Cleaning measures have a positive environmental effect and their development should be included in environmental policy.

For closed land-based aquaculture, the Water Framework Directive (WFD) has relevance for the waste output and what is being done about the water and effluents. It is of importance that there is little to no literature on anything relating closed land-based aquaculture and the WFD. But, there is literature and data for land-based aquaculture in the form of ponds, raceways, etc. due to the water being in direct contact to nature, effecting the environment, so waste is of the upmost importance, especially when it comes to problems with discharges with high levels of nitrogen and phosphorus. Poor system designs, water quality issues and mechanical problems are the main constraints of RAS (Badiolaa, Mendiolaa, & Bostockb, 2012).

However, land-based fish farming shows a positive future for aquaculture, alleviating the stresses of overfishing in the oceans and addressing the increasing food demand due to population growth. The inputs and outputs in aquaculture effect the water quality and treatment, and so must be managed effectively.

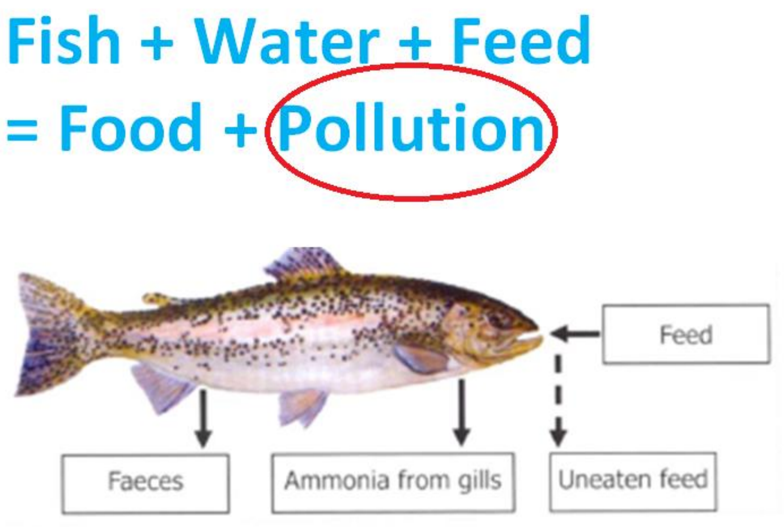


*Figure 1 Shows the input and out from fish in a recirculatory system. Pollution is highlighted here as this is what must be managed post-fish production in terms of wastewater and sludge. Source: AquaCircle*

This figure also shows that the inputs produce pollution, so not only does the management of this pollution must be monitored and remediated after production, but should also be addressed before production. This includes the "make-up" of feed; what ingredients are concerned with the consistency of feed; the quality of water being fed into the system; and the type of fish and how much feed it eats; how it metabolises the feed and how much waste it creates.

The reuse of water provides a waste to resource attitude that complies with the circular economy. *"Our vision is that the Danish aquaculture production of fish in the longer term will be in systems with recycling and cleaning water or in offshore installations in the open sea."* (Brosbøl & Jørgensen, Strategy for sustainable development of the aquaculture sector in Denmark 2014-2020, 2014).

With sustainability being a key term cropping up in everyday life of how businesses and people can improve their footprint on the world and decrease their consumption in an environmentally sustainable way, the concept of CE is also high on the agenda, with the aim of reusing materials normally deemed as waste, as a resource. ***One man's waste, is another man's treasure*** is a way of thinking circular rather than linear.

Land-based fish farms are under constant pressure with the increase in measures on water quality protection and implementation of the WFD to ensure the quantity of water used per unit fish produced is managed efficiently, and likewise with effluent treatment processes.

This leads to the following problem statement:

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*How is waste and water managed sustainably in closed land-based recirculating aquaculture systems in relation to the Water Framework Directive and other legislations?*

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## 1.1. Research Questions

To help answer the problem statement, the following research questions have been devised:

**RQ1: Why is RAS considered the "future of aquaculture" in comparison to other land-based aquaculture farms systems, and how does this relate to the implementation of the Water Framework Directive?**

This question will be addressed using the BAT document (chapter 5.1) and how this relates to the Water Framework Directive and other legislations associated, using information incorporation from chapter 0 for the analysis.

**RQ2: What are the inputs, outputs, problems and restrictions of closed land-based aquaculture fish farms, and how are these managed sustainably regarding the Waste Framework Directive and the Nitrate Directive?**

This question is addressed in chapter 5.2 and 5.3 looking at the water quality and treatment in a closed land-based system. This is further analysed using Danish Salmon as an example, through the Environmental approval and EIA.

**RQ3: How can the restrictions of closed land-based aquaculture be overcome? What methods could be used to improve the system of water quality and waste management in a sustainable manner?**

These questions are addressed in Chapter 6.2. Future research which reviews what areas should be investigated after the discussion on the whole content of the report helping provide insight.

## 1.2. Objectives

The objective of this thesis report is to:

- Identify essential gaps and provide recommendations.
- Discover the future of closed land-based aquaculture in terms of technology.
- Highlight the issues of implementing the Water Framework Directive in relation to the water used in and the waste from closed, land-based aquaculture systems in Denmark.
- Discover why there are barriers in the system regards to legislations, waste management and those responsible, and how these can be tackled and overcome.
- Present solutions and a way-forward ensuring the highest level of environmental sustainability.

## 1.3. Structure of Thesis Report

This report addresses seven chapters, as represented in the figure on the next page. A description of what will be included in each chapter is given:

| | Description |
|---|---|
| Chapter 1 Introduction & Problem Formulation | Introduces background information to the thesis topic and outlines the problem, research questions, research scope, objectives and structure of the report. |
| Chapter 2 Methodology | Includes the selection of the case, the methods and data collection, the limitations and delimitations. |
| Chapter 3 Conceptual Framework | Outlines the basis for considering the problem statement and provides an overview of the methods that can be adopted; the challenges regarding sustainability and the theory around this and the circular economy. |
| Chapter 4 Institutional Framework | Includes a review on the governance linked to land-based aquaculture farms regarding the Water Framework Directive, the Environmental Protection Act, river basin management plans, waste management of nutrient pollution. |
| Chapter 5 Analysis of Closed Land-based Aquaculture: Technology, Pollution Control & Waste Management | Addresses the best available technology, the reuse of water and reusing waste as a resource, and the sustainability aspects of this and controlling the quality of water and treatment.<br><br>Analyses of a functioning closed land-based aquaculture farm. Reviews the process of environmental approval and accreditation, and suggests new areas that could be included to help the status of sustainability within closed land-based aquaculture. |
| Chapter 6 Discussions & Future Research | Discusses the previous chapters with suggestions for future research. |
| Chapter 7 Conclusions | Addresses each research question and relates back, providing a summary. |

*Figure 2*
*Flow chart of the thesis chapters and a description of their content.*

Within this report, when land-based aquaculture is mentioned it is referring to closed recirculatory systems, unless otherwise stated.

# 2. Methodology

*This chapter introduces the case selection, the methods used and how data was collected, and the limitations and delimitations involved.*

## 2.1. Research Scope & Case Selection

Denmark was the chosen country to study due to the experience and long history of fish farming and innovations, and that recirculatory aquaculture systems is very much the "baby" of aquaculture in terms of the recirculatory farms are relatively new or have not been functioning for long.

The selection of the catchment area was first searched using the reference list of fish farms from Billund Aquaculture's website. Aalborg (Limfjorden catchment area) has no land-based fish farms, otherwise this would have been chosen due to travel distances and living in this area.

The original scope was changed when it proved extremely difficult to get access to the land-based fish farms which was also confirmed by Ottesen of Hjørring Municipality that it is a very closed industry. The fish farms are in a position where they do not want to open the possibility of being shut down. Issues/ problems they need to address and working towards.

Due to the limiting selection of fish farms in this NKSCA and being unable to meet with any and having the EIA to one fish farm then no fish species was deliberately picked to consider. In the case of using Danish Salmon, the Salmon is the fish that is produced. Again, the size of the production farm was initially thought of but in the end, it did not matter. However, the task proved worthwhile in logically thinking how to select the case, for it to be relevant and have some scientific value.

Events led to one out of the three recirculatory fish farms to be picked and focused on. The selection chose Danish Salmon based in Hirtshals due to accessibility of data and information, and the fact it has already been running / functioning in production which can be assessed in terms of the EIA and discharge permit.

However, some aspects could be applied to other areas of waste management from farms and agriculture. This is discussed later in chapter 6 with an example.

## 2.2. Methods & Data Collection

The methods used for researching this thesis topic include literature and contacting relevant people through email communication and interviews. These methods are most appropriate as this is an exploratory study questioning whether closed land-based aquaculture systems are the best technology and form of producing fish and being done sustainably with little environmental impact and ensuring water quality and waste management is also achieved in the same manner. The methods allow to see what information is currently available and highlight and question what is missing.

### *Literature review*

The methodology taken for searching the literature is as the following. Firstly, key words were selected and were used to search and identify literature using Google Scholar (websites, articles, books); Google Search (websites, articles, books); AUB Aalborg University Library (AAU - digital) (articles, books); and Nota.dk (books). The selection process was to identify useful literature by reviewing the abstract and skimming the text/chapter(s) to see whether the information is useful to my understanding. From this a hierarchal mind map (Figure 3) was created to help organise the topics into useful and visually means. To assist, draft summaries of the most relevant literature were created and referenced. This helped structure and assemble the literature review where major themes and suggestions for further research were documented.

The mind map can be seen below showing a hierarchal design of the main topics and sub-topics associated:

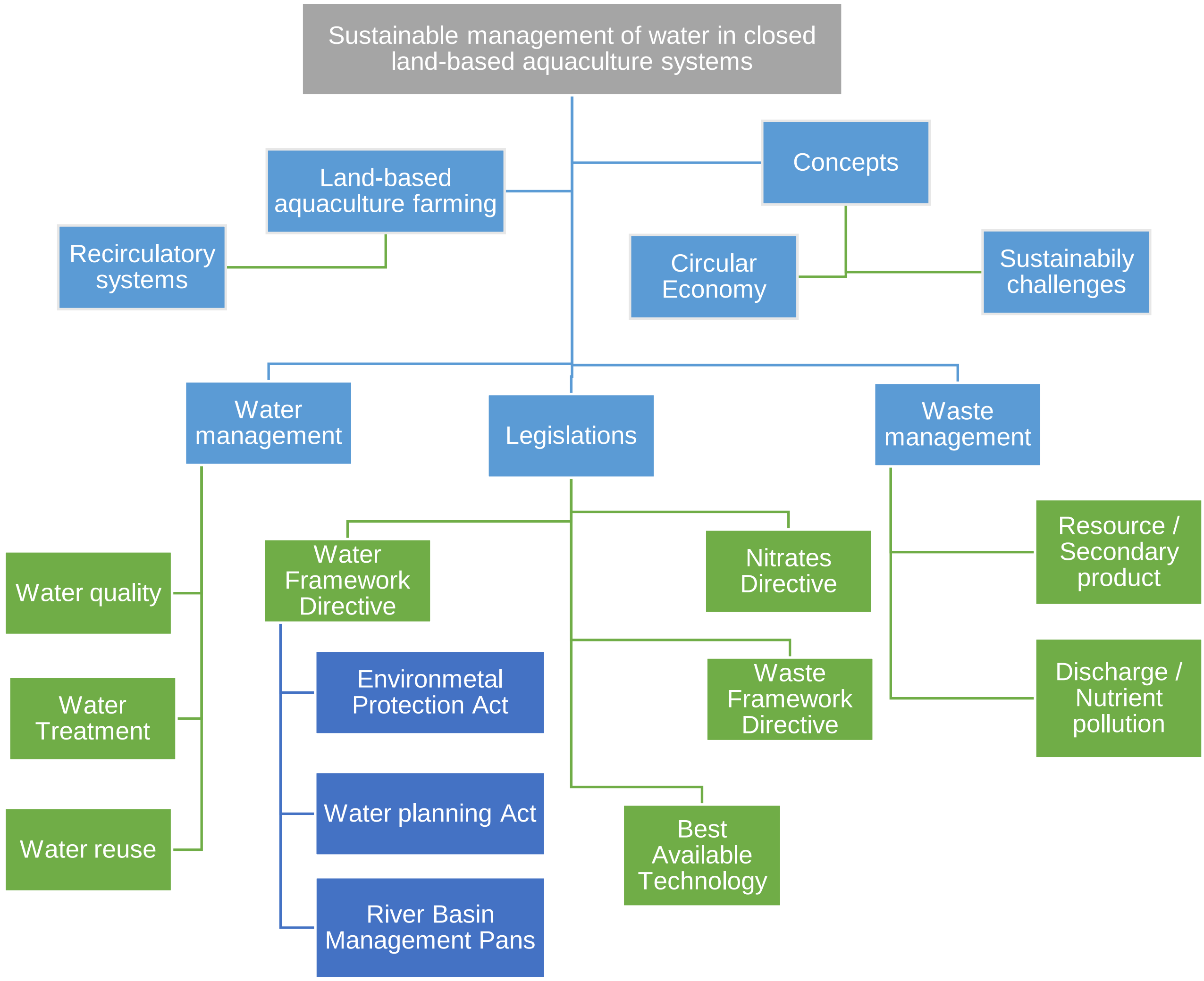


*Figure 3 Hierarchal mind map of the main- and sub-topics within the project thesis and topics researched.*

This study is largely based on (internet-based) qualitative research methods using library and information science (LIS). The goal of this study is understanding and finding out what gaps there are and what is needed to fill them or at least move in a direction that works to fill these gaps to improve the waste management and water quality in closed land-based aquaculture systems.

Information and data was used from literature and email communication from the Environmental Protection Agency (EPA), Danish AgriFish Agency, Agency for Water & Nature Management (SVANA), Dansk Akvakultur (Association of Danish Aquaculture), DHI (EIA of Danish Salmon) and Hjørring Municipality.

Initially, a search for selection of fish farms to interview was carried out via searching through the contacts lists of: Nordic Network on Recirculating Aquaculture Systems[2] member list, "List of Network Members from the Industry" and Billund Aquaculture "Reference List" to find suitable contacts to get in touch with.

Contact was achieved via telephone calls and email correspondence. However, not all persons contacted responded and thus a different direction was required, where someone else in the department/area of study could be contacted.

Originally, the first step in contact was to email the interested persons, introducing myself and the thesis topic, and opening to my interest in them and if they would be willing to have an informal meeting to discuss certain aspects. Some individuals/organisations were contacted again if a topic area needed to be clarified for my understanding and to cross-check mixed information. This also applied to checking the written work in this study and information on websites that were not clearly defined.

Regarding the three closed land-based fish farms in the NKSCA, telephone communication should have been the opening as this would give them less chance to refuse and possibly open. However, this did not happen, as two of the fish farms was unsuccessful without connecting, and one where it was a profound refusal. If the telephone calling method had worked, the next step would be to follow up with an email.

From this point, it was decided to take a different route and contact someone who has a connection with the fish farms but from an outside perspective. This is where an interview was arranged with Ottesen at Hjørring Municipality who assisted with the environmental approval process with Danish Salmon. This method had a "snowballing" effect in some respects, as some information led to was already reviewed and/or potential contact people had already been approached. However, it did open information to literature and people that otherwise may have not been discovered.

### *Email correspondence*

Using email allows for a written record which can be referred to and questioned, and allowing a tracking system of events. The assured feeling of being able to check information with those have interviewed to confirm information and understanding adds to the validity and reliability of information received. Some of those contacted who did not have the necessary knowledge to help, provided contact details for those who may be able to assist. This opened further avenues to literature and people and allowed access to data and information.

[2] "Nordic Network on Recirculating Aquaculture Systems aims at co-ordinating and strengthening the research and development of Recirculating Aquaculture Systems (RAS) in Nordic countries. Everybody with an interest in RAS are welcome to join the network" http://www.nordicras.net/Members/Industry

A table of all those contacted is given in Appendix 1 (section 7.1).

### *Interviews*

Interviews are one of the most common used qualitative methods in educational and social science research. They can be a useful tool of obtaining information and data as a single method or used alongside other useful methods. With all research, there are advantages and disadvantages to the methods used which must be recognised to make a well-rounded and transparent analysis (Weare).

Below is shows the advantages and disadvantages associated with conducting interviews:

| Advantages | Disadvantages |
|---|---|
| Obtain higher quality information | Time consuming than other methods |
| Ask more complex questions | Likelihood of bias |
| Request further explanation | Lack of experience in interviewing |
| Can build rapport with the interviewee | Miscommunication |
| The structure can be less structured | Geographic's |
| Observation of the interviewee | |
| Can expect a high response rate | |
| Can retrieve more information than you otherwise would via a different method | |
| Visual aids can be used | |
| Any language barriers or uncertainties can be questioned and clarified | |

*Figure 4 Advantages and disadvantages of conducting interviews (Weare).*

The structure of the interview can be achieved in three main ways:

- **Rigidly structured** – essentially an oral questionnaire which allows for re-phrasing or probing questions.
- **Semi-structured** – questions are asked around themes and topics. Set questions can be used as a guideline.
- **Non-directive** – highly exploratory, with the interviewer not probing for responses. (Weare).

Interviews were one of the chosen methods for this study, alongside literature and email communication to gain insight where questions asked could lead to further information and knowledge growth.

However, the scope changed when interviews with the fish farms could not be secured.

The following table shows the two interviews and the different method used.

| Name | Organisation | Type of interview | Method | Date |
|---|---|---|---|---|
| **Nethe Ottesen** | Hjørring Municipality | Semi-structured – non-directive | Face-to-face | 1st May 2017 |
| **Jacob Bregnballe** | AKVA Group | Semi-structured – rigid | Telephone | 16th May 2017 |

*Table 4 Overview of interviewees and the interview method.*

***Nethe Ottesen, Hjørring Municipality (Environmental Permits)***

A face-to-face interview with Ottesen at Hjørring Municipality proved to be valuable being able to discuss the problems in environmental approvals, the technology associated and where else I could look for information and who I could contact. The interview was recorded with details of questions discussed in Appendix 2 (Chapter 7.2). Some notes were taken during the interview which have been used in the report and to find further information. The recording was used to confirm other areas and to ensure information was written correctly. What is written was confirmed for use by Ottesen and permission of the recording to be submitted alongside this report was given.

***Jacob Bregnballe, AKVA Group (RAS Technology company)***

The other interview was a telephone interview which lasted around 40 minutes. The call was not recorded. Answered questions were written by the interviewer during the informal discussion. It was difficult to understand some of the conversation due to a poor signal. Permission was given to use the information received from Bregnballe.

### *Access to information*

Deciphering of information is not an easy task, especially for Municipalities who want to ensure production plants perform to a high standard environmentally but also to ensure the business is not harmed. Information of the fish farms which is available for public access is normally in the form of only the approvals and permits given by the Municipality to the fish farm.

The Aarhus Convention of 1998 is an initiative that allows the public certain rights to voice their opinion in decisions that affect environmental quality. The convention represents *"a commitment to access to information, participation in decision-making and access to justice on environmental matters."* In terms of the environmental impact assessment and the environmental permit this is the case, but difficulty in finding an EIA for the other fish farms in the NKSCA.

## 2.3. Limitations

There are some aspects these methods of literature, email communication and interviews may not be able to assist and explain. This includes the fact that access to the fish farms in the NKSCA was not granted, nor any exchange of information. However, information and data for Danish Salmon was found through the help of Hjørring Municipality on the terminology (in Danish) to use in searching for necessary documents accessible to the public through the internet and similar resources.

Much of the literature used was English written literature due to the researchers own delimitations. However, some text in Danish has been referred to and used by translating the text. On occasion, where text has been too large, an interpreter has been used to summarise the contents, or only parts have been translated that were viewed as the most relevant. This could be a disadvantage if something has been overlooked.

## 2.4. Delimitations

For this study, it was chosen to focus on the environmental sustainability and does not consider the economic or social aspects of sustainability, despite the inclusion of the circular economy, which addresses socio-economic aspects as well as environmental.

The thesis project originally aimed to interview three closed land-based fish farms using recirculatory water technology, however this was proven extremely difficult due to this industry being extremely closed and private, not wanting to share their knowledge. Thus, this has not been included in the report. However, outside factors associated but not in direct with the three fish farms have been contacted for their expertise and knowledge and access to data. A change in considering biomimicry has also been altered, due to not having access to the fish farms, and a focus on the governance has been the major topic of interest and accessibility.

Originally, the exploration of biomimicry as a method for management and treatment of water and waste, but due to not being able to discuss and having no access with the fish farms it has not been a focus.

Another delimitation is 1 week before hand-in the minutes to the **Good Practice Workshop on Sustainable Aquaculture (Baltic Region)** from 12$^{th}$-13$^{th}$ June 2014, Ministry of Foreign Affairs of Denmark, Copenhagen, was discovered, which has a lot of useful information and with more time could be analysed more thoroughly and the people that attended and gave presentations could have been contacted for an interview or other.

# 3. Conceptual Framework

*This chapter outlines the conceptual framework of sustainability and the circular economy and how each in recent years are receiving great attention and power in the academic, industrial and policy maker's worlds. These concepts are what can be used to ensure the sustainability and waste reuse in closed land-based aquaculture systems.*

## 3.1. Sustainability Challenges

In the context of this report and the framework to be used, the challenge of managing water quality and wastewater in a sustainable way, and how it can be achieved environmentally is the main aim. Improving water quality, recycling and reusing "waste" as another resource are actions that have increasing attention and are high on the agenda.

Sustainability is an emphasising factor as aquaculture on land increases and is recognised as forward-thinking innovative solution to production of healthy protein food source and using limited water. The World Commission on Environment and Development (WCED) wants to help secure sustainable development within aquaculture and believes it is a measure that can be achieved (Bardach n.d.). With this, the sustainability of waste must also be addressed and included into action plans remediating and mitigating against discharge.

Relating to the overpopulation, overconsumption and water being a finite resource, sustainability management theories can provide better guidance of how systems can advance for a more sustainable future. This can be increasingly useful when other management theories fail to include sustainability on the agenda. Widen the disciplines so they are not only economics, psychology, political science, business and public affairs, but include natural science, philosophy, other social science, i.e. sociology and anthropology, medicine, engineering, public health, education and law (Starik & Kanashiro, 2013). Having a holistic viewpoint across disciplines sharing knowledge is a crucial factor to include. Attention to long-term perspectives is key to implementing sustainability, not as short- to mid-term perspectives which can lead to suboptimal decisions and failure to invest and afford current and future technologies that could have a positive impact on sustainability. Learning is key to the development of sustainability management and survival of humans, where education should be high on the agenda to ensure value and understanding of the natural environment humans live to ensure co-existence (Starik & Kanashiro, 2013). Sustainable management certificates could be awarded, for example, for water efficiency, reuse and waste reduction (Starik & Kanashiro, 2013).

*Sustainable Development Goals*

The SDGs are a list of goals aimed at providing guidance on how to improve key areas sustainably and how each person can make changes to their lifestyles to make a difference and help the development of the world in a sustainable way in which everyone can live in harmony without exploiting resources, ensuring each resource is managed responsibly and effectively.

*Two of the Sustainable Development Goals (SDGs) are associated and linked to this project; water management and the circular economy.*

**SDG6** (ensure availability and sustainable management of water and sanitation for all) – in this case the goal would not apply for "sanitation for all" but could be applied to closed land-based aquaculture systems and the water and waste management involved.

**SDG12** (ensure sustainable consumption and production patterns) – in this case with respect to the circular economy.

The reality is that most existing legislation was developed for linear production and consumption patterns, and this ideology is in the process of change to a circular model, which is explained in the next sub-chapter 3.2.

The goals were introduced in September 2015 so are relatively new and not implemented within land-based fish farming, but could be considered as an aim/ commitment to improve the sustainable management of waste by implementation and monitoring regarding water resource management and waste resource management.

The interesting questions arising here aimed for the fish farmers would be; where do land based fish farms stand regarding the subject of sustainability, and do they measure their environmental impact, maybe in the form of carbon footprint measurements?

## 3.2. The Circular Economy

*Water, waste and the circular economy.*

Resource flows in a circular economy can help resource scarcity. With an increase demand in clean water and healthy food, the economy is no longer suited to being a linear model as modern societies cannot build a future on a "take-make-dispose" model. Movement to an environmentally economically sustainable system is required through a circular and life cycle thinking to preserve the many natural finite resources (European Commission, 2015) (International Water Association, 2016).

The circular economy is a fast and upcoming concept that replaces the standard, known, linear economy for the circular economy of reducing, reusing and recycling. In day-to-day life;

personal, business, industrial, etc. it should be the aim to embrace the principles of the circular economy and make use of what otherwise would be a wasted resource.

The concept of the circular economy was first developed in the 1970's by an architect, Walter Stahel, who realised that the economy was unsustainable and linear. With growing consumptive demand, the demand for raw materials increases and in turn creates waste accumulation. This leads to serious problems in the future, and so rethinking the value chain and closing the loops is something to aim and work towards. The mentality of the CE is described as a free philosophy (Vos, et al., 2016). Reducing waste to a minimum.

Water is a valuable resource that must be treated with respect and methods to conserve this precious resource put in action like the circular economy concept of reuse.

The treatment and reuse of wastewater is under-exploited in Europe and show to be a promising option relating the circular economy and environmental sustainability. Regarding agriculture and aquaculture the reuse of wastewater helps contribute to nutrient recycling (European Commission, 2015).

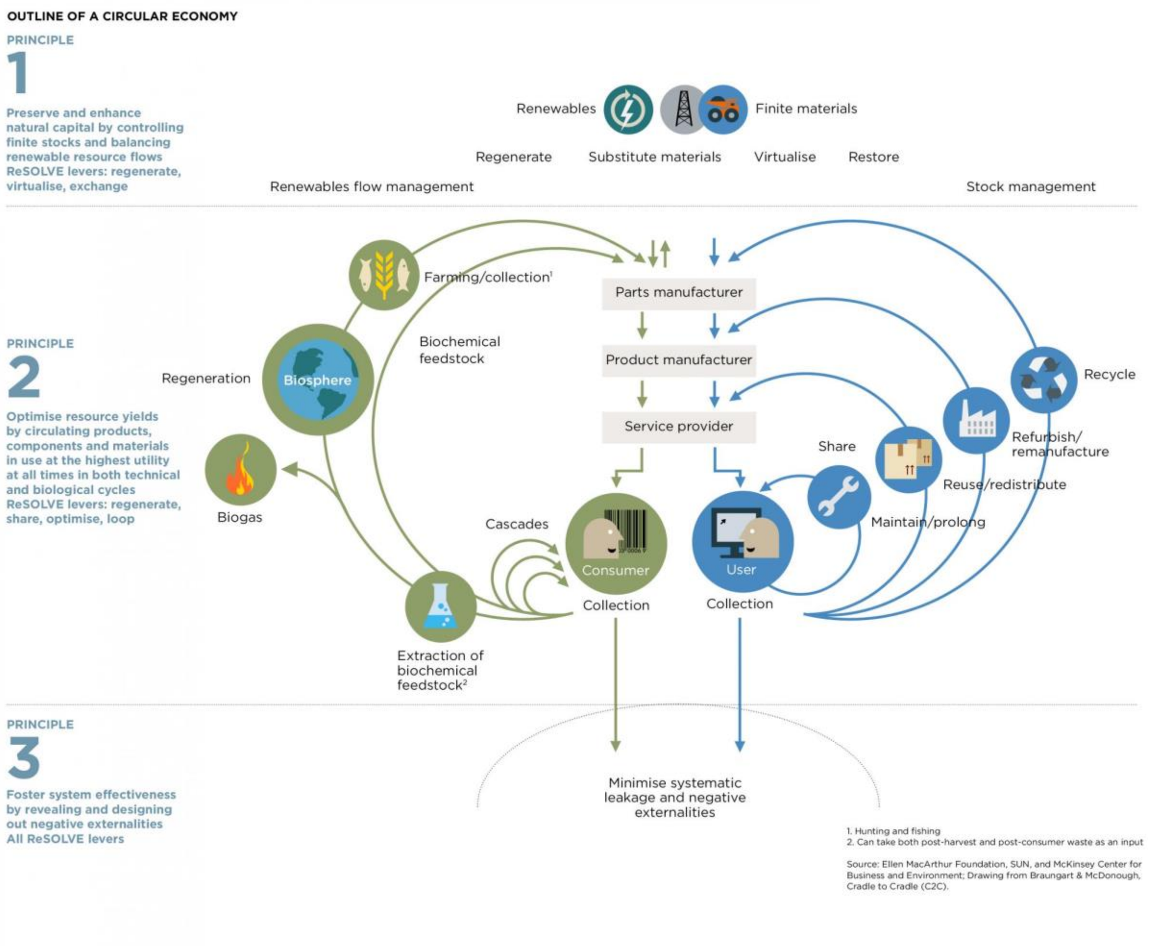


*Figure 5 The Circular Economy Concept (Ellen MacArthur Foundation, 2015).*

This project considers the left side of this diagram on renewables management and the farming/collection including hunting and fishing. The traditional way of land-based fish farming is with flow-through systems which is a linear way of managing a fish farm. Using the circular economy concept, recirculated aquaculture systems (RAS) focus on a circular/reuse style of thinking by reusing the water in the system and feeding it back into the tank system. This reduces the amount of water required and the amount of "dirty" water released. Another specification of RAS is the water treatment facility within the fish farm to manage and clean the water. This ensures water is to the optimum conditions of quality for the fish and for the environment. Within RAS, there is research for the management of effluent waste and how that can be utilised as a resource instead of being thrown out as waste.

The theory that if you repair, reuse, recycle is that there is less waste and harm in the environment. This can be more manageable and counter-productive.

*"Wastewater treatment plants are part of the old paradigm; we now think of and design resource factories, energy generators and used water refineries. Whereas the conventional imperative was to remove pollutants, it has now shifted to reuse and recycle resources."* (International Water Association, 2016).

### *Circular Water Economy*

A quarterly magazine by the International Water Association (IWA)[3] created an article on "*The Role of Water in the Circular Economy*" asking a panel of professionals about the vital role water can play in the CE. The panel of professionals consisted of three Professors and a Head of Public Administration Projects. The interview refers to the new ambitious Circular Economy Package adopted by the European Commission (Michell, 2016).

Following is a summary of the questions and responses, quoting the professionals from the interview.

Regarding the importance of the new series of actions and how beneficial these could be for the CE, it is believed that is a "good start" (Leeuwen, 2016)[4] and "necessary not only for the water sector, which requires urgent action… but also for the circular economy itself" (Elelman, 2016)[5].

[3] The International Water Association (IWA) is a non-profit organisation and knowledge hub for the water sector with an interdisciplinary global network of water professionals, connection scientists, practitioner and communities. IWA develop research and projects focused on new solutions for water and wastewater management; organise events; aim and help to put water on the global political agenda and influence best practice in regulation and policy making (International Water Association (IWA), 2016).

[4] Professor Kees van Leeuwen, Principal Scientist, Chemical Water Quality and Health, KWR Watercycle Research Institute.

[5] Richard Elelman, Head of Public Administration Projects, Fundació CTM Centre Tecnològic (Advanced Technological Centre).

Following this, the question "*Why has water not really been considered as a vital part of the circular economy?"* In response, Drewes[6] states that water is recognised too late as a vital part of the economy, and quotes Benjamin Franklin: *"When the well is dry, we know the value of water."* Showing the importance of water and the need to reuse this finite resource (Drewes, 2016). In addition, Verstraete[7] believes that "more focus on coherent urban strategies on governance and transitions in cities" are missing, and that the European Commission need to become future-thinking rather than "old thinking" in terms of legislation (Verstraete, 2016). Elelman points out from a political perspective that water "has been easier to ignore in comparison to media-friendly issues such as solid waste collection, energy, ICT and public transport." (Elelman, 2016).

The importance of including water in the circular economy "is absolutely critical… as a cornerstone" regarding water being a limited resource (quantity and quality), and the seasonal availability being challenged by climate change (Drewes, 2016). Leeuwen explains that "in 2013, the European Commission published its approach for smart cities, limiting it to ICT, transport and energy. Water, waste and climate change were not included." (Leeuwen, 2016).

The legal, technical and political bottlenecks that stand in the way of a circular approach to water include "a lack of supportive and coherent framework for water reuse, limited awareness of benefits among stakeholder and decision makers, and frequently a misperception in the general public regarding the safety of this practice." This can be caused to using correct terminology and ensuring opportunities are not missed for reusing water in areas where water is overexploited (Drewes, 2016). Verstraete believes that we have the means to achieve a circular approach to water, however, "major obstacles in terms of culture and religion… where resentments-taboos-slow down our politicians in taking legal actions to recognise that we can recover resources from used water." (Verstraete, 2016). Governance is the real and principal bottleneck, not technology, according to van Leeuwen and Elelman further adds that the concept of CE and similar theories and concepts are "misunderstood or completely ignored by 99 percent of the population, including those responsible for ensuring the legal, technical and political consensus required to enable the continuity of the long-term implementation of broad urban plans." (Elelman, 2016) (Leeuwen, 2016).

Michell states that "water could be described as the most important shared resource across all supply chains, yet wastewater is the largest untapped waste category" and asks why this

[6] Professor Jörg E. Drewes, Chair of Urban Water Systems engineering, Technical University of Munich.
[7] Professor Willy Verstraete, Head of the Laboratory of Microbial Ecology and Technology, Ghent University.

is.  Drewes believes this is true probably due to perception as “we grow up with the notion that wastewater is something that smells, is bad and something to get rid of, but 99 percent of wastewater is still water.”  Wastewater should be recognised as a resource opportunity not a disposal problem (Drewes, 2016). The other professionals share the same consensus.

The most dangerous outcome of the exclusion/lack of focus on water in the circular economy is not progressing as a society and implementing better technologies (Verstraete, 2016). Leeuwen believes that “scientist should not stop telling the European Commission that excluding water is the blunder of the century.  In the end, common sense will prevail.” (Leeuwen, 2016).

Water is often seen as a policy afterthought due to “the lack of recognition and appreciation of its true value.” Education of water and its benefits needs to be included in schools at an early age and continue throughout teaching children the importance and understanding of water (Drewes, 2016).  Verstraete states the problem that water is taken for granted and viewed as a basic human right and so can be disregarded despite its upmost importance.  “Demand must be created” for governments, stakeholder and policy makers to work together synchronising knowledge to create a better future for the inclusion of water reuse (Verstraete, 2016).

The concept of circular economy is one method of working towards sustainable management of a closed land-based aquaculture fish farm. The following chapter introduces the Water & Waste Framework Directive and other legislations associated and which are connected to land-based aquaculture.

# 4. Institutional Framework

*This chapter outlines the governance associated with water and waste management, specifically looking at the Water Framework Directive and the Waste Management, and the Acts, Plans and Directives associated. It opens the knowledge gaps of where and how these plans, rules and regulations are associated and could be applied to closed, land-based recirculatory aquaculture farms, focusing on what is missing and should be included*.

## 4.1. Water Governance

### 4.1.1. Water Framework Directive

The Water Framework Directive (2000/60/EC) was adopted in 2000 by the European Union which introduced a legislative approach to managing and protecting water, natural geographical and hydrological formations: river basins, and based not on national or political boundaries. The WFD's aim is for "*waters must achieve good ecological and chemical status, to protect human health, water supply, natural ecosystems and biodiversity"* by 2015 and no later than 2027 (European Commission, 2010). The purpose of the WFD was to ensure overall consistency of water policy in the EU as the European water legislation had become very complicated. (Frederiksen & Maenpaa, 2007).

The WFD is a framework for future water protection whereby water meets high quality standards in future generations. (Lanz & Scheuer, 2001). The uniqueness of the WFD is that it relies highly upon all those concerned in taking an active role and responsibility in implementing the legislation. Water and quality. Integration of policies and actions. Objectives of sustainable water use (Water Wisdom).

The implementation of the WFD in Danish legislation was achieved in 2004 as the Law of Environmental Objectives (discussed in sub-chapter 4.1.3) (European Commission, 2012).

Implementing the WFD and preparing the RBMPs is carried out responsibly, ensured they are established and that environmental objectives are met under the Ministry of Environment, the approving authority.

Within this project, the main element of concern is waste water discharge from the fish farms.

The Urban Wastewater Directive provides information for industrial waste water and has the purpose to protect inland and coastal waters, and the environment from possible pollution and discharge of waste water from the industry. This can be monitored through appropriate collection and treatment. A biological treatment process with a secondary settlement is typically used. Guidelines and specifications for the building of wastewater plants are provided in the directive (Water Wisdom). Treatment does not include the disposal of waste, but the legislation specifies that what waste that can be reused, must. Regarding waste, this is addressed in Chapter 4.2. Waste Management (Chapter 4.2.2. Nitrates Directive).

Below shows the timetable of action for the implementation of the WFD/EOA. A condition is that it requires the coordination of different EU policies as set out below:

| | |
|---|---|
| **2000** | Adoption of the Water Framework Directive by the EU. |
| **2003** | Transposition of the Water Framework Directive into Danish legislation (Environmental Objectives Act) and identification of river basins and designation of the water management authorities responsible for the basins. |
| **2004** | Preparation of the Article 5 Analysis, including characterization of the river basins, registration of protected areas and an assessment of the risk that water bodies will fail to achieve their environmental objectives with the measures already adopted. |
| **2007** | 2nd half-year: Idea phase for preparation of river basin management plans and programmes of measures during which the public can contribute ideas and concrete proposals. |
| **2008** | Publication of the draft river basin management plans and programmes of measures. |
| **2009** | 1st half-year: Second public participation phase during which all stakeholders can comment upon the draft river basin management plans and programmes of measures. |
| **2009** | Final adoption of the river basin management plans. |
| **2012** | Programmes of measures to be operational. |
| **2015** | At minimum “Good status” to be achieved by all surface waters and groundwater bodies. |
| **2016** | A new river basin management plan period begins. |

*Table 5 Shows a summary of the Water Framework Directive/Environmental Objectives Act (Taken from Layman’s Report, Odense RBP)*

This summary shows the timeframe of the adoption of the WFD and its implementation and changes in Danish legislation (Environmental Objectives Act). Analysing and synthesising European legislation in relation to water (Frederiksen & Maenpaa, 2007).

The WFD does not contain explicit obligations to aquaculture. However, aquaculture activities must comply with the requirements of the WFD. The interaction and impact of aquaculture with the environment is assessed in terms of reducing wastes and effluent – assessing the environmental sustainability

Of the aims of the WFD those associated directly with the recirculating of water in aquaculture systems and the waste effluent are:

- "*to promote sustainable water use based on long-term protection of available water resources,*
- *to aim for increased protection and improvement of the aquatic environment including through specific measures for the progressive (continuous) reduction of emissions, discharges and losses of priority substances and cessation or phase out emissions, discharges and losses of priority hazardous substances*
- *to ensure the progressive reduction of pollution of groundwater and prevent further pollution"*

The main reason why and importance of distinguishing and defining between pre-WFD and WFD measures becomes an issue is that *"the legal driver for each measure is typically not reported by those who implement the measures."* The ultimate difference is pre-WFD has basic measures, whereas the WFD has supplementary measure. However, this is not clearly stated and can cause situations where the baseline for an assessment is required and the basic measures are unknown to be pre-WFD or WFD, which shows that the "WFD measure is not an implementation issue, but an ex-policy evaluation issue" (COWI, 2010).

### 4.1.2. Environmental Protection Act

The purpose of the Environmental Protection Act of 1998 "is to contribute to safeguarding nature and environment, thus enabling a sustainable social development in respect for human conditions of life and for the conservation of flora and fauna. *The objectives of this Act are:*

- *to prevent and combat pollution of air, water, soil and subsoil, and nuisances caused by vibration and noise,*
- *to provide for regulations based on hygienic considerations which are significant to Man and the environment,*
- *to reduce the use and wastage of raw materials and other resources,*
- *to promote the use of cleaner technology, and*
- *to promote recycling and reduce problems in connection with waste disposal."*

(Danish Environmental Protection Agency (DEPA), 1999).

These objectives can relate to closed land-based fish farming in terms of preventing pollution, reducing and reusing materials and using cleaner technology. These aspects are stated in the Act regarding "promoting recycling and cleaner technology and to reduce problems in connection with waste disposal" (Danish Environmental Protection Agency (DEPA), 1999).

The National Monitoring for Aquatic and Terrestrial Environment (NOVANA) is a monitoring system that integrates national monitoring of the environment and nature. In 2007, NOVANA's management needs were adjusted to include the implementation of the WFD and the Habitats Directive in the Environmental Objectives Act (NOVANA).

The NOVANA Order 2009 was a new monitoring programme, which ran from 2011-2015 and said to be more compliant with the WFD, as the previous monitoring programme followed the pre-WFD (European Commission, 2012) (Svendsen, L.M; Norup, B. (eds.), 2005).

### *Environmental Impact Assessment*

An Environmental Impact Assessment (EIA) is an analytic tool to help prevent, minimise and control negative environmental impacts with the objective of including environmental considerations in planning and decision making. It allows a transparent basis for applicants, the public and the authorities to consider environmental issues when a project or otherwise has plans to develop, despite if it is either the first time or to extend. This allows final steps in the decision making to be considered (Kørnov, Thrane, Remme, & Lund, 2007). EIA is a basic measure in water planning and a part of the WFD. The following figure shows the important steps in the methodology of the EIA process:

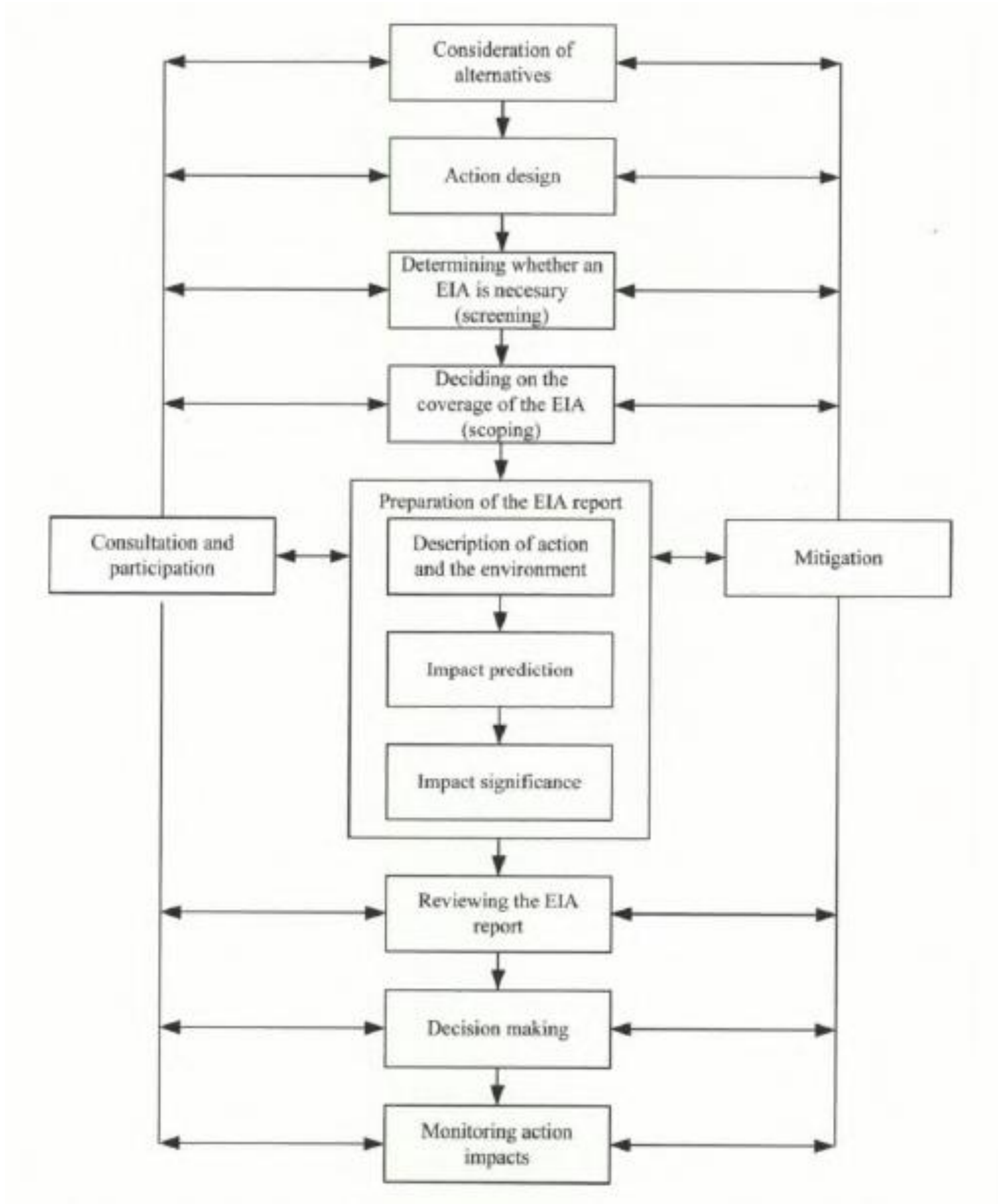


*Figure 6 The EIA important steps in methodological process (Wood, 2003).*

The inclusion of sustainability and the development of this in more environmental ways, for example using cleaner technology, to include and identify other alternatives is very important. The amended EIA Directive (97/11/EEC) includes the discussion of alternatives in article 5, stating “an outline of the main alternatives studied by the developer and an indication of the main reasons for his choice, considering environmental effects (Kørnov, Thrane, Remme, & Lund, 2007).

The Environmental Impact Assessment for Danish Salmon is analysed in chapter **Error! Reference source not found.**.

*Environmental Approval*

Under the Environmental Protection Act, certain kinds of production plants must have an environmental approval before the start of construction and production, or before expansion, etc. For aquaculture, there is a list of the types of production facilities that require an environmental permit called an approval statuary order. It includes a list of numbers relating to production type from saltwater to freshwater, from ocean to full recirculation. This is the case for closed land-based aquaculture farms. An environmental application for a permit is submitted to the Municipality of the area who oversee enforcement. The Municipality follows guidelines made by the Environmental Protection Agency. It is the responsibility of the Municipality to ensure implementation of the WFD and other legislations associated are considered and recognised. A decision is made and can include recommendations that must be achieved in a certain timeframe to carry on production.

Decisions reached by the Municipalities can be filed against in complaint at the Nature Protection and Environmental Board of Appeal.

### 4.1.3. Water Planning Act & River Basin Management Plans

The implementation of the WFD in Denmark is through the Act on Water Planning (2013). The Act is a law which *"aims to establish a framework for the protection and management of surface and groundwater…, promotes sustainable waster use based on long-term protection of available water resources…, ensures progressive reduction of the pollution…"* All water bodies in DK have been divided into 4 water districts and 23 natural river basins [catchment areas] (each with their own water plan). (Groundwater Management Practices edited by Angelos N. Findikakis, Kuniaki Sato, 2011).

Denmark is divided into 4 river basin districts: Jutland of Fyn, Sjæland, Bornholm and International.

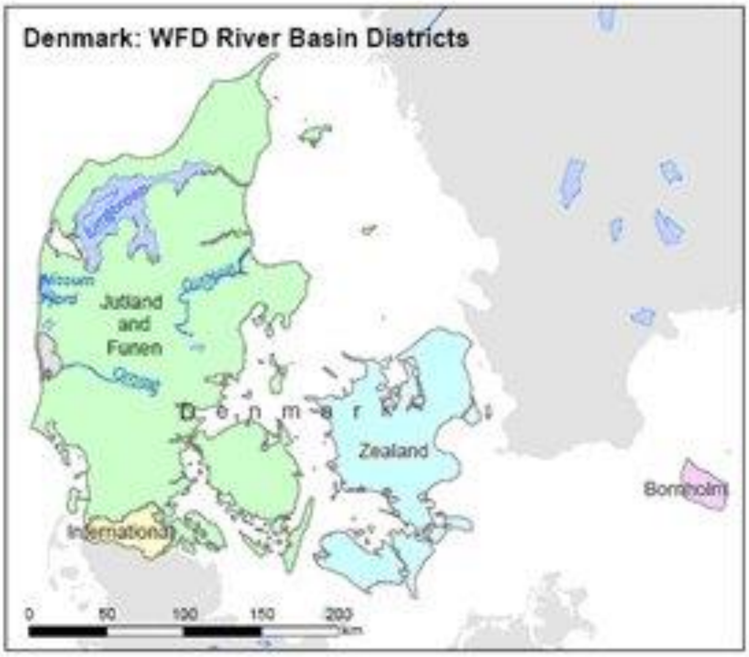


*Figure 7 The river basin districts in Denmark as set out by the Water Framework Directive*

This research project looks at the Water District Jutland and Fyn (Vanddistrikt Jylland og Fyn), Nordjylland, and the Water Catchment Area (afvandingsområde eller vandopland) of Nordlige Kattegat, Skagerrak.

The River basin management plans (RBMP) are the main management tools under the WFD and act as an information tool describing how Denmark should implement the directive (The Danish Environmental Protection Agency, u.d.). RBMPs are key to the implementation of the WFD.

In line with the WFD and the aim to achieve "*waters must achieve good ecological and chemical status, to protect human health, water supply, natural ecosystems and biodiversity"* by 2015 and to carry on the implementation and management of water, the RBMPs have different stages: the 1st RMBPs (2009-2015) and the 2nd RBMPs (2016-2021). On 30th October 2014, the Danish Government approved the 23 RBMPs which were adopted and published by the Danish Nature Agency. The second stage of the RBMPs with statuary orders on environmental objectives and programmes of measures (legally binding aspects of the planning instruments) were adopted and signed on 24th June 2016, taking effect on 1st July 2016 (European Commission, 2016).

A water area plan for each of the water districts were created and published in June 2016 by the Agency for Water & Nature Management (SVANA), now a single agency with the Environmental Protection Agency.

## 4.2. Waste Management

### 4.2.1. Waste Management Directive

The Waste Management Directive (75/442/EEC) of 1975 "…determines that a cradle to grave, duty of care responsibility for waste lies with producers of waste. Farms both produce and use waste; trends suggest exemptions for some processes, which are deemed beneficial to agriculture, may be withdrawn (Brady J. , 2005).


*Figure 8 Waste Management Hierarchy (European Commission, 2016).*

In coordination with the circular economy, the above diagram shows how the management of waste should be tackled initially, with preparing waste for reuse as a first port of call.

In terms of recirculating aquaculture systems (RAS), water that would be considered waste is sent through a water treatment facility (an installation part of the fish farm) where most water can be treated and reused into the fish tanks. For waste such as faeces, food and nutrients, some is already used for fertiliser for agriculture or bio-fuels. But, is this done at all facilities and how much is reused and recycled? What are the barriers associated, and/or why do some fish farms drop the responsibility when it comes to waste they have produced? Could this be something to consider in a change in governance? Additionally, a change in the fish farms frame of mind and way of thinking? Especially, when most of these farms, as a business sell their product on the assumption of sustainability, which to the consumer will imagine this as an all-round process to the final product and was management so waste must be considered.

### 4.2.2. Nutrient Pollution

Nutrients includes nitrates, phosphorus and organic matter (NPO). In fish farming, the nutrients are the wastes produced from feeding fish in aquaculture systems. Ammonia and nitrites are toxic to fish and cause problems environmentally when in excess amounts.

The production of nitrogen in fish farms is an issue. Research has been carried out on finding out if this harmful environmental product will increase as fish production will increase. Nielsen concluded that growth can be achieved without increased emission (Nielsen, 2015). Therefore, it is important to aim to further the management and reduction in these harmful nutrient levels, especially when there is no adverse effect on production growth of fish.

In 1985, Denmark created a Water Treatment Plan under the Water Action Plan which aimed to limit nitrate and phosphorus, Organic matter (NPO Plan).

### *Nitrates Directive*

"The Nitrates Directive (91/676/EEC) from 1991 aims to protect water quality across Europe by preventing nitrates from agricultural sources polluting ground and surface waters and by promoting the use of good farming practices." (The Danish Environmental Protection Agency (EPA), u.d.). The Nitrates Directive is an integral part to the WFD and vice versa, both measures implement to achieve the environmental objective set by the WFD (Jørgensen, 1999).

### *The Danish Action Plans for Aquatic Environment*

The Danish Action Plans for Aquatic Environment (APAEs) provide strict goals for the reduction of nitrogen and phosphorus discharges. There are three APAEs, the first in 1997, the second was accepted as the Danish Nitrate Action Plan implementing the Nitrates Directive in 1988, and the third was set in 2004 with new goals because of the success in discharge reduction from APAE II. The latter APAE (III) had a stronger focus on reducing phosphorus by 50% and nitrogen (compared to 2001/2) by 13% by 2015 (compared to 2003) (Danish Nitrates Action Programme 2008-2015, 2012).

### *Green Growth Agreement*

Green Growth Agreement of 2009 continued the goals of Plan III. The agreement is so wide that it undertook its own nitrate action plan which complements the agreement (The Danish Environmental Protection Agency, 2009); (The Danish Environmental Protection Agency, u.d.).

In 2012, a new aquaculture legislation was created to change the allow the environmental burden of a fish farm to be determined by fish production and not the production size as with the previous regulation. Instead, the regulation would be based on nutrient discharges, not fish feed quotas (Suhr & Jokumsen, u.d.).

### *Reduction of Nitrogen*

According to the *"Strategy for Sustainable Development of the Aquaculture Sector in Denmark 2014-2020"* states that the government's objective that the average nitrogen load per. tonne of fish produced is to be reduced in 2020. However, this can counteract the government's wish for aquaculture production on land to increase (Brosbøl & Jørgensen, Strategy for sustainable development of the aquaculture sector in Denmark 2014-2020, 2014).

A nitrogen removal project by *Aquabest* was carried out to test more efficient technologies in nitrogen removal within model trout farming as within this system nitrogen is the least retained nutrient (Suhr & Jokumsen, u.d.) The most important process of removing nitrogen is called *denitrification*. "It occurs when denitrifying bacteria in the absence of oxygen utilizes nitrate ($NO_3^-$) for energy generation according to the equation:

$$5\,CH_3COOH + 8\,NO_3^- \rightarrow 4\,N_2 + 10\,CO_2 + 6\,H_2O + 8\,OH^- \qquad (2.86\text{ g COD/ g }NO_3\text{-N})$$

(Suhr & Jokumsen, u.d.)

Results from *Aquabest's* project showed that "rearranging the effluent RAS flows could significantly improve nitrogen removal by denitrification." Organic matter produced internally is an area which is not taken full advantage of in most RAS facilities (used as a carbon source for the denitrification process) (Suhr & Jokumsen, u.d.), which would create more circular thinking of reuse and development sustainably in the management of "waste" as a valuable resource.

# 5. Analysis of Closed Land-Based Aquaculture: Technology, Pollution Control & Waste Management

*This chapter provides an overview of closed land-based aquaculture waste management, including the best available technology, water quality and treatment in recirculatory systems and the reuse of "waste" (water and waste/sludge), and the sustainable aspects surrounding these elements. Here, the research questions are addressed.*

Legislation for fish farming was tightened between 1987-1989, where the following aims were introduced:

- Reduce water intake,
- Minimum standards for feed and conversion rate,
- Criteria's on oxygen level in water to ensure less disease,
- Standard cleaning technology – to reduce emissions by 20 %

(Heldbo J. , Short introduction to Denmark and prospects of Danish aquaculture, 2015).

All Danish aquaculture farms (excluding full recirculation eel farms) must be officially approved in accordance with the Environmental Protection Act (see chapter 4.2.1.) (The Danish Environmental Protection Agency).

The Environmental Protection Agency provides guidelines for the environmental authorities and oversee the implementation of the WFD. The Municipalities carry out inspections at the fish farms and have full authority in the decision-making process on the responsibility of following the guidelines incorporating all necessary legislations, including the WFD.

## 5.1. Best Available Technologies Reference Document

This section addresses research question 1: Why is RAS considered the "future of aquaculture" in comparison to other land-based aquaculture farms (LBAF) systems, and how does this relate to the Water Framework Directive implementation and other legislations of governance? (this second part of the question is answered in more detail in chapter 7) In doing so, the Best Available Technologies (BAT) Reference Document is considered with the report "BAT for fiskeopdræt i Norden" (BAT for aquaculture in the Nordic region) in view of discovering how BAT can be used and applied to reduce the environmental impact of aquaculture in the Nordic countries.

The concept of the Best Available Technologies (BAT) is to reduce the effects of environmental impacts based on the best available technology which additionally is economically sound. The use of BAT is closely related to the environmental goals such as the WFD, with the shared aim of achieving "good status" in all aquatic areas.

The "BAT for aquaculture in the Nordic region" report considers how BAT can be used and applied to reduce the environmental effect of aquaculture (Heldbo, Rasmussen, & Løvstad, 2013). Techniques for RAS are given. Technological solutions for reducing environmental impacts of aquaculture are described in detail due to the technological advances in Denmark being developed intensely through research and development. (Heldbo, Rasmussen, & Løvstad, 2013). The document also provides an evaluation section on land-based production. A major aspect to the best available technology regarding land-based aquaculture is the consideration of water purification technologies. Additionally, advanced technology that reduces pollutants and other environmental hazards are appraised and potential opportunities given (Heldbo, Rasmussen, & Løvstad, 2013).

Traditional Danish fish farms known as flow-through systems are beneficial in terms of low technology usage, in turn making the functioning of the fish farm cheap. However, the downside to this, is the abstraction of surface water which can lead to pathogenic organisms and pollutants in the fish farm affecting the fish, and the fluctuation in oxygen content (Heldbo, Rasmussen, & Løvstad, 2013). Additionally, the wastewater once run through the system can be released back into the environment and effect the existing habitat with elevated levels of nutrients, i.e. nitrogen, phosphorus and organic matter, with which the environment could be highly sensitive.

In the past 5-10 years, development of fish farming technology has been significant, especially regarding recirculatory aquaculture systems. Those that can fully recycle water are said to be the future of aquaculture, also because of the extensive environmental requirements that must be met in terms of discharge of pollution, and the systems allowing better control and management of fish production. Water treatment in land-based fish farms is primarily associate with nitrogen, phosphorus and organic matter. Technology included with treating the water includes the accumulation of biofilters, sludge dams, oxygen and UV/ozone (for water purification) (Heldbo, Rasmussen, & Løvstad, 2013).
As the main challenges in the future rely on decreasing environmental impact, this "new" technology provides opportunities for development and potentials of resource reuse.

## 5.2. Water Quality & Treatment

Water quality regulation concerns the control of discharge that may have negative environmental impact on the environment. Factors that depend on the amount of impact include: the amount discharged; the location/management of the released discharge; and the use of the water (Brady J. , 2005).

Using different technologies has an impact on the treatment of water and the removal of waste. This can be shown in the following graph taken from AquaCircle PowerPoint presentation:

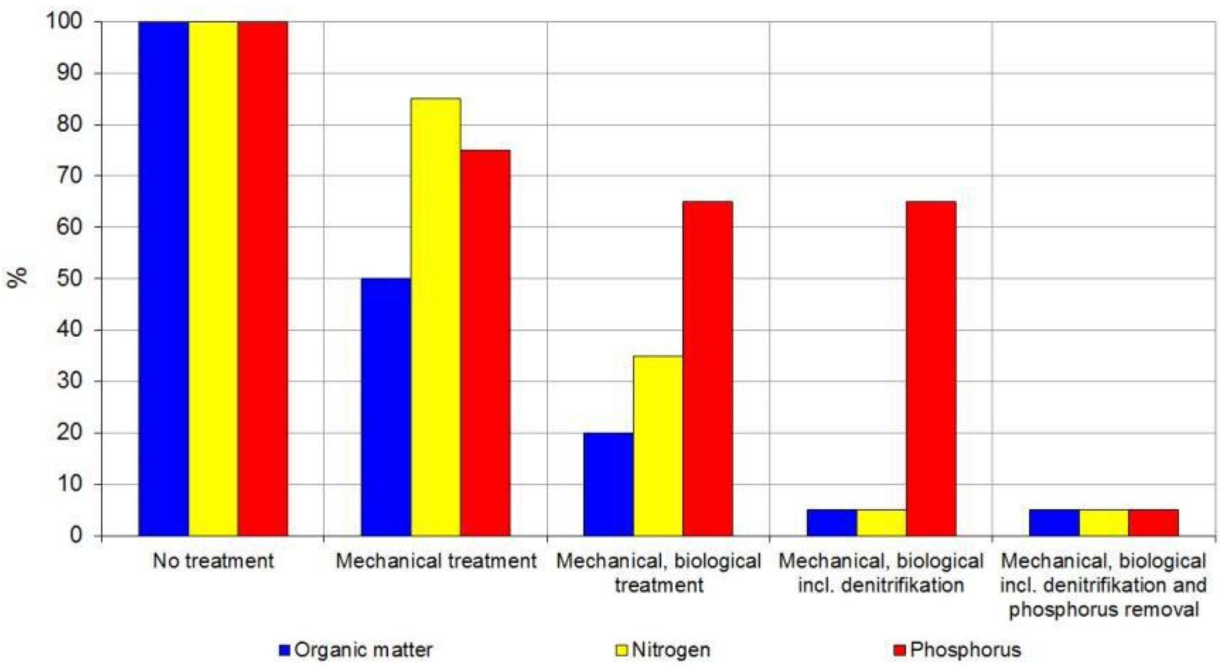


*Figure 9 Source: AquaCircle (Heldbo J. , Short introduction to Denmark and prospects of Danish aquaculture, 2015).*

With increased treatment, the more effective reduction in nitrogen, phosphorus and organic matter. There is a significant difference in percentage volume of waste of N, P and OM when the systems include denitrification and phosphorus removal. It also shows that even though mechanical and biological treatment help decrease levels of N, P and OM, there is still a high percentage that can impact the quality of the water and discharge.

Facilities are normally constructed with several water treatment loops to contain any diseases that may occur, which allows it to be contained in one compartment and dealt with, instead of having one water treatment loop which then containment is difficult and the disease could spread to the fish (Heldbo J. , Short introduction to Denmark and prospects of Danish aquaculture, 2015).

The traditional flow-through system allowed for oxygen to be added into the system when new water was inputted and flowed through. With a RAS, oxygen is still inputted with the small amount of water added.

The main difference in these two systems is the amount of water used (water consumption).

RAS processes include:

- Solids removal
- Biological treatment
- Gas control – oxygen injection/CO2 degassing
- pH adjustment – alkalinity control
- pathogen control – UV/ozone dosing
- Waste/sludge management

These processes maintain a healthy water quality and manage the removal of unwanted nutrients.

Feed compositions affect water quality and with future competition of feed resources, the effect of the feed is an integral part to the quality of the water and the waste produced.

There is a lot of research and developments into water treatment within RAS and how to decrease the waste load of nutrients dangerous at certain levels to the environment and

Biofloc technology can be used to manipulate the C/N ratio where toxic nitrogenous waste into can be converted to "useful microbial protein and helps in improving water quality under a zero-exchange system" (Ahmad, Rani, Verma, & Maqsood, 2017).

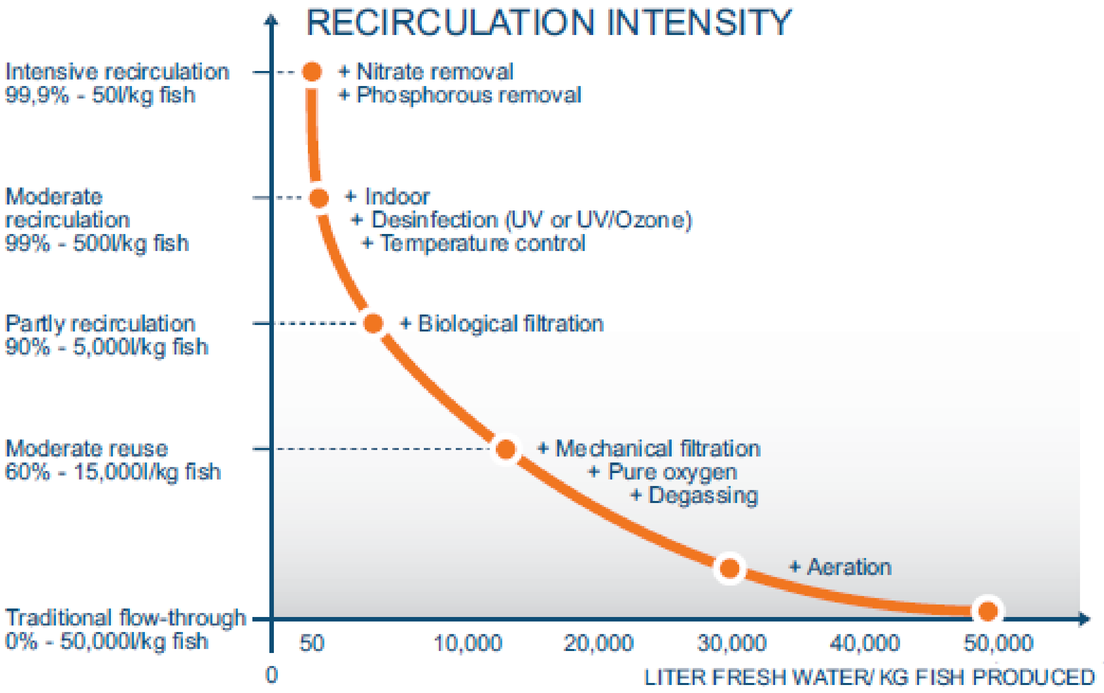


*Figure 10 Recirculation intensity – graph showing the amount of water in litres required to produce 1 Kg of fish using different systems; flow-through opposed to recirculation. Source:*

The reuse of water is already happening in the utilities, everyday water we use from the sink tap, shower, toilet is clean and fresh. Once we have used it and it goes down the drain or is flushed away, it travels to a cleaning / treatment facility operated by the Municipality. The water is cleaned and makes its journey back to houses. This application of reusing water is applied in RAS, where up to 99% of water can be reused. This is a positive change in water use compared to the traditional way of farming fish in flow-through systems

Another positive in the reuse of water is when it comes to filtration and furthermore the type of filtration used, e.g. biofiltration which is a naturally occurring process, it does not require any use of chemicals. Using the biofilter allows the ammonia to be detoxicated and nitrification to take place where a bacterial conversion occurs.

## 5.3. Case Study of Danish Salmon

*The previous chapters have outlined and given information on the water framework directive and other related legislates, environmental standards, and closed land-based aquaculture technology and water and waste management. This chapter takes this information into an analytical stage and applies it to Danish Salmon, a closed land-based fish farm in Hirtshals (Nordlige Kattegat, Skagerrak catchment area).*

Nordlige Kattegat, Skagerrak Catchment Area (NKSCA) is one of 23 catchment areas in Denmark. NKSCA is located in Nordjylland, the Northern part of Denmark.

*Figure 11 Map showing the Nordlige Kattegat, Skagerrak Catchment Area highlighted in dark blue (Miljøstyrelsen, u.d.).*

Within this catchment area there are three closed land-based RAS fish farms; one in Hirtshals and two in Hanstholm. For this study, one of the fish farms, Danish Salmon in Hanstholm will be analysed, as described in Chapter 2: Methodology (2.1. Case Selection).

Danish Salmon is a land-based fish farm using a recirculatory aquaculture system located in Hirtshals, in the catchment area of Nordlige Kattegat, Skagerrak. The production start was April 2015. The production amount (tons per annum, t/a) is 2,000 t/a salmon. Danish Salmon have two objectives; protecting the environment and sustainable production.

AKVA Group technology which has 99% recirculation degree. Danish Salmon chose to set up the technology and equipment themselves, however it may have been beneficial taking advantage of the specialists within this technological area.

In 2015, Danish Salmon experienced waste management issues and water temperature control – lost several months of Atlantic Salmon production due to excessive elevated temperatures (Warrer-Hansen, 2015). This would have been very interesting to enquire about and discussed if an interview could have been set.

### *Environmental Approval & Impact Assessment*

An Environmental Approval was granted and issued to Danish Salmon by Hjørring Municipality on 09 May 2017. Information gathered here is from using the "Environmental Approval" Document which is a document publicly accessible. It includes information from the EIA produced by DHI, which was a document also used. Hjørring Municipality determined that Danish Salmon can be established and continue production without causing significant amounts of environmental pollution to the surrounding area. Danish Salmon uses the best available technology and have necessary measures implemented with the sole purpose of preventing pollution discharge (Ottesen & Meyer, Environmental Approval Danish Salmon - Discharge Permit and License, 2017).

Danish Salmon's EIA Statement of changes in operation, Environmental Impact Assessment (EIA) was prepared by DHI, specialists in water, was completed 23rd August 2016 in compliance with the ISO9001 for quality management.  There are many areas and assessments that were carried out, with the most important relating to water and waste including an "assessment of possible environmental impacts, sources and types of influence – pollution, water recovery, water quality, including discharge from wastewater treatment plant.  Water purification and sludge treatment.  Establishment of denitrification plant is a requirement for the reduction in nitrogen production." (Birkeland, Dannisøe, & Hansen, 2016).

The EIA showed that nitrogen to be considered the biggest source of pollution. The discharge license provided the following requirements to Danish Salmon of the maximum discharge acceptable:

| COMPONENT | PER YEAR | PER DAY (AVERAGE) |
|---|---|---|
| EMISSIONS | 31.1 million. m 3 | 3,600 m 3 |
| NITROGEN (N) | 45 tons | 123.3 kg |
| PHOSPHORUS (P) | 3.9 tons | 10.7 kg |
| ORGANIC MATTER (BOD5) | 58 tons | 158.9 kg |
| COD | 170 tons | 465.8 kg |

*Table 6 Shows the allowed discharge limits for Danish Salmon set by Hjørring Municipality*

This environmental permit allows for 45 t of nitrogen discharge per year.  It is known that Sashimi Royal is permitted to discharge 48 t nitrogen per year.  However, the catchment area is already in a deficit of 183 t nitrogen per year.  This is an area of upmost importance which requires assessment for the whole area, especially with a nitrogen quota of 380 t nitrogen (aquaculture) (Birkeland, Dannisøe, & Hansen, 2016) (Ottesen, 2017). The interview with Ottesen at Hjørring Municipality discussed these numbers and the origin source of the 380 t nitrogen quota, of how it was determined.  This was one area that was difficult to seek out.

## 5.4. Sustainability Certification

### *Aquaculture Stewardship Council*

The Aquaculture Stewardship Council (ASC) is a certification scheme set up by the **WWF** (World Wide Fund for Nature) and partners for sustainable aquaculture.

"ASC (Aquaculture Stewardship Council) is a labelling scheme which was established in 2009 by WWF and the Dutch Sustainable Trade Initiative (IDH) in order to promote responsible farming in aquaculture and fish farms. Together they have developed global ASC standards for 12 fish species." (Dansk Akvakultur, u.d.).

"WWF is involved in the work on environmental labelling ASC, which should make fishing for farmed fish (aquaculture) more sustainable over the world."

*Figure 12 ASC logo that shows certification of responsibly farmed fish*

The most important requirements of the ASC in terms of the environment are:

| | |
|---|---|
| **1.** | To avoid changes to the sea and land environments around the fish farms<br>The location of the fish farm is assessed in relation to protected areas, habitats of endangered species and natural wetlands |
| **2.** | **Good water quality** |
| | In order to ensure good oxygen conditions in the waterways, there is a minimum limit for oxygen saturation in the effluent water from the fish farms. Phosphorus is used as an indicator of how good a fish farmer is at minimising the discharge of nutrients per ton of produced fish. |
| **3.** | **Minimising of negative effects on water resources** |
| | Demands are made on the fresh water supply to both surface and ground water. Ensuring sufficient free water in waterways to maintain flora and fauna also requires that at least half of the flow of water to the stream must flow freely past the fish farm. |
| **4.** | **Handling of waste** |
| | An overview map of the flow of water and waste, a plan for handling sludge, an operation journal of sludge handling must be prepared and spillage of sludge and other biological substances into the surrounding area is not allowed. |

*Table 7 Describes the most important requirements of the ASC in terms of the environment. Source: taken from the Dansk Akvakultur website (Dansk Akvakultur, u.d.)*

This certification is not only good for consumers to know the fish they source is sustainable and healthy but also that the production and the fish farmers have produced to a high standard and abided guidelines and constantly reviewing and improving. This is what should be done to constantly ensure to meet the standards of the certification as well as the other legislations, such as the WFD as described in the previous chapters.

# 6. Discussions

### *Waste management post-production*

The management of waste is not always included in the process of fish farming and can be failed to be mentioned when fish farms apply for environmental permits. This can also be overlooked by Municipalities if they are not using and referring to the correct and available legislations. These governance challenges are something that can create starting points for the input and suggestions for policy makers

Practices put in place currently and environmentally are done so to a certain criterion and an acceptable amount of, e.g. nitrogen to be discharged, or how to mitigate once a level too much has been released. Nevertheless, practices should be put in place before these levels are too high, already try to decrease them and start and function at a lower production level

Why is it that it appears that the focus in land-based recirculatory aquaculture, that production is the main environmental focus, and the waste from post-production is "forgotten?" Fish farmers don't follow legislations and directives directly, such as the water framework directive, but are informed of and rely on the levels they should abide to by the Municipality, who has guidelines from the EPA. Do these fish farms not want to do as much as they can to consider the waste and how to manage it environmentally and in a circular thinking manner? An interest in what happens after production, e.g. the waste can highlight an area that should be considered within the entire process. Considering a life cycle perspective will also assist in the management of waste.

The compliance of environmental legislation should be obligatory.

### *Environmental Responsibility*

The Environmental Liability Directive (2004/35/CE) is a transitional directive with the role of improving the legislative framework. Regarding waste disposal that cause environmental harm due to certain activities than liability for the clean-up is to those responsible (i.e. they will have to pay to remediate the situation). The aspects behind this could be considered for the inclusion of fish farmers and responsible people in closed-land based aquaculture facilities.

### *Implementation of WFD & Suggestions*

The implementation of the WFD is not always thought of and forgotten. Thisted Municipality approved an environmental request for Sashimi Royal based on their application, but this did not include what is to be done with waste and so certain rules, i.e. on the amount of nitrogen produced and released was not considered in terms of the WFD and so too much is produced with no action plan in place.

Need to integrate specialised companies, i.e. DHI to manage the waste and furthermore create possibilities such as waste resource and creating industrial symbiosis.

Unity in Municipalities is required providing the same level of working, e.g. Sashimi Royal being approved without the WFD being considered, hinders Danish Salmon who has a "disadvantage" in that sense when it comes to functioning and producing, but an environmental target to work towards, obtain and sustain. Something to be considered is that as Sashimi Royal had no complaints over their application, they now have 8 years to run as they are with no implications of having to change.

### *Future of land-based aquaculture – research and development*

It is important that the future of fish farming advances technologically to ensure an increase in reducing electricity/energy costs and reducing nitrogen production into the environment.

Fish farms wanting to produce more fish to market can potentially outweigh the environmental concerns and cause more harm, producing more nitrogen that can be managed, causing great local harm. Additionally, this situation is worse when smell/noise pollution is created.

### *Water consumption*

Lessons could be learnt from the little use of water in comparison to other animal production farming methods, i.e. cattle (cow, pig, chicken), also the control management of the water conditions. Coming from the water angle, water-related diseases (especially in developing countries) require clean accessible water and in turn food. LBAF could assist? The RAS technology can be adapted and applied in various locations in the world with a scarcity of clean water where enough could be supplied to the fish farm. This would allow the production of fresh fish using clean water (which otherwise, using pre/traditional technology is unhealthy and nonenvironmental in some countries, such as Bangladesh. Also, the adaptation of the WFD could be applied if a country outside the EU wants to put into action this directive and ensure environmental standards are to the upmost quality standards, and implementation of reuse of "waste" is put in place.

Could something be put in place to measure the exact amount of waste at the end, so as not to wait and rely on calculations? Then the exact data can be assessed sooner rather than later, and not wait, say a year to realise that too much nitrogen, for example has been produced. It allows for long-term thinking.

### *Applying waste management in other areas of agriculture*

**Månegrisen (moon pig)** – is a public-private partnership initiated by Ministry of Food in December 2012. *"The vision is to abolish the contradiction between the expansion of pig production and environmental, climate and animals. Moon Pig will provide input for future emissions based regulation, which involves measuring the actual emissions from each farm,* *which requires new measurement technologies"* This is an ambitious concept where technology and regulations have not been developed and hence the name "moon pig" as it is making a comparison to putting a man on the moon (Landbrugs og- Fiskeristyrelsen, 2017).

Could aspects of waste management in closed-based aquaculture be applied here, and vice-versa?

### *Sustainability*

Prospects of the future of the sustainability within aquaculture is a positive one. Moreso, with the content research and development seeking a clean alternative.

Land-based fish farming in recirculatory aquaculture systems make a good case for a clean alternative to traditional ways of farming on land, such as ponds, raceways, etc., and open-ocean cages. Productivity, performance and reliability are aspects that distinguish RAS from other methods of fish farming and this is hoped to improve with further development and management of environmental legislation.

The fish farms in the NKSCA each promote sustainability, but what does this mean exactly? Elements are sustainable, but to what degree and can this be misleading? In terms of waste, this is an issue but should it be a disposal problem or a valuable resource? The latter is the ideal and forward-long-term-thinking.

Another way of ensuring that closed land-based fish farms function and produce fish to a high standard and within environmental limits with the attitude of constant revision and improvement is nominating the farm for certification.

As said in chapter 5.4.3. Sustainability Development Goals could, these could be adapted and implemented for closed land-based aquaculture.

## 6.1. Limitations

The hope for an interview with Danish Salmon was unsuccessful despite email and telephone contact. Firstly, refusal, then ignored, and then a blunt no. The reasons were that Danish Salmon are not interested now for sharing their knowledge and that they do not have time as they are busy with production, despite being offered a less demanding Skype interview.

Difficult finding the exact number of closed land-based fish farms situated and functioning in Denmark. The Danish Environmental Protection Agency cannot give an exact number and is an approximate. Data should be concise and up-to-date records must be kept, also to ensure proper management across the Municipalities with regards to these fish farms. Due to competition, there is a high level of closed/shut-off behaviour, which could be damaging overall.

## 6.2. Future Research

*This thesis has looked at the question of sustainable management of water from a political science perspective in terms of governance and the legislations in place. In some aspect within this there is elements of natural science when discussing the quality of water and the biology associated. Further work that could work alongside in a transdisciplinary fashion would be to look further into this section of biology within technology and how legislations and change in mind of creating solutions pre-production, not only post-production can be achieved.*

The discourses following from issues such as the responsibility of whether the EPA should take more of a role in including data from closed land-based recirculatory fish farms and monitor the progression, not only the Municipalities. Closer communication and analysis of the guidelines provided by the EPA to the Municipalities could be explored.

*Responsibility & discharge data*

The responsibility of discharge from land-based fish farms is primarily the fish farms and the Municipalities. A better shared knowledge base would help. A possible research question into reviewing this could be: **How can communication between the industry, governance, NGOs, and the public be improved?** Technology that measures the inputs and outputs more frequently provide better data to be analysed and assessed to help make decisions and guidelines on the amount of discharge that can be allowed without impacting the environment. Furthermore, the amount of fish being produced and the amount and type of feed being used, which effect the water quality and waste can be assessed pre-production, to ensure waste can be managed sustainably and the amounts determined prior. There is a calculation that is used to estimate this already, but could this be improved and a better system used. Also, that data can be retrieved instantaneously instead of waiting a year or so to deliver the amounts.

*Waste as a resource*

Waste can also be used as a secondary product, as a resource. For example, lettuce can be grown from the nutrients from fish farming. This is called aquaponics, where fish and vegetables are grown simultaneously. Environmentally and economically viable.

Aquaponics is another area which uses plants that use the discharge from the fish and "waste-" water. The system helps improve water quality and reduce water discharge (recirculated to plants) and management of nitrogen disposal (by plants). Plants such as lettuce can be harvested. This uses the circular economy concept of waste being used as a resource in another area. The system is a self-containing one but also has issues on larger commercial scales, and tend to be developed on a smaller scale.

A potential question could be: **Is fertiliser and biogas the only forms of reuse of the "waste"? What methods are available?**

### *Biomimicry*

In nature, there is no waste. Looking to nature for ideas and how to limit and manage our waste is a positive outlook which could be applied to the management of waste in RAS. This concept is called biomimicry, which is essentially used to "consult" with nature for innovative and sustainable ideas and designs that can be 'mimicked' instead of exploiting natural resources and ecosystems. Could there be methods to improve the reduction of nitrogen and phosphorus discharge produced via fish farming. **The development of effluent treatment systems currently use biofilters – could these adapt the concept of biomimicry? Are there other areas in the system that could use this method for treatment of water and waste? Fish themselves treat water in their bodies through filtration – could this be an example that could be used?** Discussions with the fish farms would be ideal to discuss research and development and create a collaboration to improve the future of land-based aquaculture. Here, it was proven a challenging task, but maybe in the future or it may be the case of a certain company/organisation working with the fish farm that could get insight, working together to achieve sustainable management of water in closed land-based aquaculture systems.

# 7. Conclusions

*This is the concluding chapter of the report of what was researched and addressing each of the research questions. In the previous chapter, Discussions & Future research an in-depth discussion was given on all aspects, here a summary of this linked with answering the research questions is given relating to the conceptual and institutional frameworks in chapter 3 and 4 respectively.*

**RQ1: Why are recirculating aquaculture systems considered the "future of aquaculture" in comparison to other land-based aquaculture farms systems, and how does this relate to the implementation of the Water Framework Directive?**

This question was addressed in chapter 5.1. and used the BAT document to analyse the best available technology for land-based aquaculture and how this related to the WFD and other legislations. Incorporation of chapter 4 for the analysis. It was found that recirculating aquaculture systems with a high degree of recirculation are a technology with constant research and development that is expected to grow in the future. Better technology for reducing harmful and toxic nutrients. In relation to the WFD, recirculating aquaculture systems require far less water than traditional ways of farming fish on land. This allows for better management to ensure the water is of "good status" and not discharged into the environment leaving it affected by pollution. The wastewater discharged must reach minimum environmental levels to guarantee safety. However, these data levels may need revaluation, also depending on the catchment area and what additional pollution problem there is, despite if they are not from the closed land-based fish farm.

**RQ2: What are the inputs, outputs, problems and restrictions of closed land-based aquaculture fish farms, and how are these managed sustainably regarding the Waste Framework Directive and the Nitrate Directive?**

This question was addressed in chapter 5.2 and 5.3 looking at the water quality and treatment in a closed land-based system. Here, Danish Salmon, a fish farm based in Hirtshals was analysed in terms of water quality and waste management of discharge using the Environmental approval and EIA documents. In conclusion, it was found that fish food is the primary cause to the levels of nutrients (nitrogen, phosphorus and organic matter). From this, denitrification is a positive process of reducing the level of nitrogen discharge, especially in the case of Danish Salmon, as nitrogen was identified as the key problem in pollution discharge. Additionally, sludge waste can be used as a carbon source in this process of nitrification, so reuse of the waste to reduce harmful nutrient waste.

**RQ3: How can the restrictions of closed land-based aquaculture be overcome? What methods could be used to improve the system of water quality and waste management in a sustainable manner?**

This question was addressed in the previous chapter in 6.3. Future Research. Restrictions were discovered in the access to information and finding the source origin to certain data.

The use of "waste" as a resource and incorporating the circular economy. Additionally, the increasing area of aquaponics could be further researched and how this could function successfully on a commercial scale.

Other potential methods of water treatment could include biomimicry, or other areas in the production cycle that may have not been thought about.

Overall, this study has provided a stepping stone and an opening into further questions for Municipalities and other interested/associated parties. The study has not been totally conclusive and requires more research into sustainable methods into the pre- and post-production of fish on land, incorporating up-to-date legislation specific to closed land-based aquaculture systems.

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# Appendices

## 7.1. Appendix 1 – Contacted Individuals/Organisations

| Organisation | Contact Name & Position | Contact Details | Reason for Contact |
|---|---|---|---|
| | Mark Russel (M.R.) | Savvaerksvej 3<br>5400 Bogense<br>Danmark<br><br>Email - mru@markrussellaqua.com<br><br>Tel +45 50118481 | Interview (Danish Salmon)<br><br>Comment: M.R. no longer works at Danish Salmon, so gave me the contact details to the present plant manager.<br><br>Contacted again after K.N. (plant manager at D.S refused an interview) to see if he can help with who else I could talk to – who would be willing? I had no response. |
| **Danish Salmon** | Kim Nielsen, Plant Manager (K.N) | Phone: +45 31 12 72 20<br>Mail: kim@danishsalmon.dk<br><br>Danish Salmon A/S<br>Niels Juelsvej 46<br>DK-9850<br>Hirtshals, Denmark | Interview (unsuccessful due to not wanting to share knowledge) |
| **Royal Danish Fish** | Lars Lynge, Production Manager | lly@royaldanishfish.com<br>Direct: +45 9655 0501<br>Mobile: +45 2210 0230 | Interview (unsuccessful due to no response) |
| **Sashimi Royal** | Bent Urup | +45 2630 6000 | Interview (unsuccessful due to no response) |
| **Hjorring Municipality** | Nethe Ottesen | nro@hjoerring.dk | Information / Data<br><br>Interview held on 1st May 2017. |
| **The Danish Protection Agency** | Thomas Bjerre Larsen | +45 72 54 41 53<br><br>thobj@mst.dk | Info/Data/No. of I-b fish farms in DK<br><br>Email communication – information given and advised to contact SVANA. |
| **DHI (experts in water environments)** | Mads Joakim Birkeland | mbi@dhigroup.com | Info/Data/English version of EPA for Danish Salmon<br><br>No response |
| **AquaCircle** | Jesper Heldbo, General Secretary | Tel: (+45) 43 54 41 31<br>Mobile: (+45) 40 22 22 60<br>jesper@aquacircle.org<br>www.aquacircle.org | Data<br><br>Email communication – sent a PowerPoint presentation on RAS. |
| **Danish Environmental Protection Agency** | Sara Westengaard Guldagger<br><br><br>Bente Brix Madsen, | sawgu@svana.dk<br><br><br><br>bebma@mst.dk | Info/Data/No. of land-based fish farms in Denmark<br><br>WFD / Legislations<br><br>Contacted back by Madsen on behalf of Guldagger, |

| | | | |
|---|---|---|---|
| **(DEPA) and SVANA[8]** | Marine Biologis/Water Planning | +45 41 96 94 17 | Response from Bente Brix Madsen, Marine Biologist/Water Planning at the EPA. |
| **KRAV** | Kjell Sjodahl-Svensson | Kjell.Sjodahl-Svensson@krav.se | Information.<br>Response: KRAV do not award closed land-based aquaculture farms KRAV certificate as follow the EU organic rules |
| **AKVA Group[9]** | Jacob Bregnballe | +45 75513211 | Telephone interview held on 9th May 2017. |

*Table 8 Shows the different organisations contacted for information for this project report.*

## 7.2. Appendix 2 – Interview Questions

**<u>Nethe Ottesen, Hjorring Municipality (Environmental permits)</u>**

**Environmental Rules & Regulations**

1. What are the rules and regulations associated with the functioning and management of a closed land-based fish farm?
2. Do these rules only apply to the functioning and management or do they begin during the planning and construction phase?
3. What rules/regulations must be followed for the treatment of water and waste?
4. Are there any advisable rules/regulations that are not mandatory but should be? If yes, why are they only advisable?
5. Are there any standard certifications that must be passed to run a functioning land-based fish farm?
6. Are there any standards that must be in place to achieve controls for optimum water quality? If yes, what are these?
7. How could the Water Framework Directive be implemented through the Act on Water Planning within Danish land-based aquaculture farms?
8. Is it already being done? How is it explained/described to fish farms?
9. Do closed land-based fish farms follow this framework through the Act of Water Planning or is there another process in the hierarchy of the directive?

[8] SVANA (Styrelsen for Vand- og Naturforvaltning) is the Agency for Water and Nature Management, whom from February 2017 are a part of the EPA (SVANA and the EPA are a single agency).
[9] AKVA Group are a global company specialising in aquaculture technology, including RAS technology.

**Water/Waste amount, management & treatment**

10. How are fish farms monitored in terms of environmental health safety? In terms of the quality and health of fish, water and waste?
11. Do you know if 'waste' is measured, and how much can be treated and reused? Is any?
12. What is the main problem with waste-water and effluent? How is this dealt with? What methods are in place?
13. Is temperature an issue in Recirculating Aquaculture Systems – that the heat produced can be an issue and needs to be cooled? Could this outweigh an environmental befits and be a negative impact?

**Sustainability**

14. What is your understanding of Sustainable Aquaculture?
15. What are the key areas in closed land-based aquaculture that need attention in terms of the environment?
16. What is your understanding of 'bionik' (biomimicry)? How do you think this could help waste management and water problems associated with land-based aquaculture farming?

**Access to information**

17. Why is the land-based farm industry closed to sharing information?
18. Is this the case for the whole of the aquaculture industry?
19. What advise do you have as to how this could be changed to ensure improvements for the environment and shared knowledge?

## Jacob Bregnballe, AKVA Group (RAS Technology company)

**Sustainability**

1. What is your understanding of Sustainable Aquaculture?
2. What are the key areas in closed land-based aquaculture that need attention in terms of the environment?

**Construction & Design**

3. How many fish farms have you supplied equipment to?
4. I was told that Danish Salmon use your equipment but they installed it themselves. Why did they chose not to use your expertise? Is this the case with other fish farms?
5. Where do you receive ideas for the equipment made – innovative

6. How do you design the parameters, i.e. flow, water change, feeding capacity? Do you have a research team, for example, who research the amount of Nitrogen levels that should be monitored and filtered, and how this is incorporated into the design of equipment?
7. What is your understanding of 'bionik' (biomimicry)? How do you think this could help waste management and water problems associated with land-based aquaculture farming?
8. In most the literature, I have seen and read, the designs show circular or rectangular tanks on one level. Have you researched into the amount of land and space required?

**Technology**

9. I have recently heard about RAS+; how does this differ from RAS?
10. What methods of filtration are used? Others? What is the effectiveness?
11. Can 'waste' be measured by your equipment?
12. I have been told one of the crucial issues with RAS is the control of the temperature - that the heat produced can be an issue and needs cooling. Is this true? Could this outweigh an environmental befits and be a negative impact?

**Rules & regulations**

13. Are there any legislations or standards that you must meet the requirements of?
14. Do you have any power or say in the management of the technology?