Workshop:

Macroalgal cultivation on Faroese fjords

- the need for environmental assessment and monitoring

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TARI FAROE SEAWEED

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Contents

1. Introduction

As part of the project *A Sustainable and resilient macroalgal cultivation industry in the Nordic and Arctic Region (ASuReMacro)* funded by the Nordic Council of Ministers, a workshop was held on the 15th of March in the cultural centre SALT in Suðuroy on the Faroe Islands titled *Macroalgal cultivation on Faroese fjords - the need for environmental assessment and monitoring.*

The workshop was organised with presentations from the ASuReMacro project partners each representing different key aspects and expertise on topics related to macroalgae cultivation. In addition were invited key speakers from selected Faroese stakeholders, representing both from the public sector and industry. After the presentations there was an informal panel discussion where everyone could make comments and ask questions. The informal atmosphere throughout the workshop, ensured a great environment where people felt comfortable discussing opportunities and challenges in the macroalgae industry in addition to key environmental issues.

The workshop was moderated in the Scandinavian language and was open to the public. Around 20 people attended the workshop (Figure 1.1). The two Faroese macroalgal cultivation companies were well represented in addition to researchers from Fiskaaling and people from the public sector representing both the food and veterinary authorities and the environmental authorities.

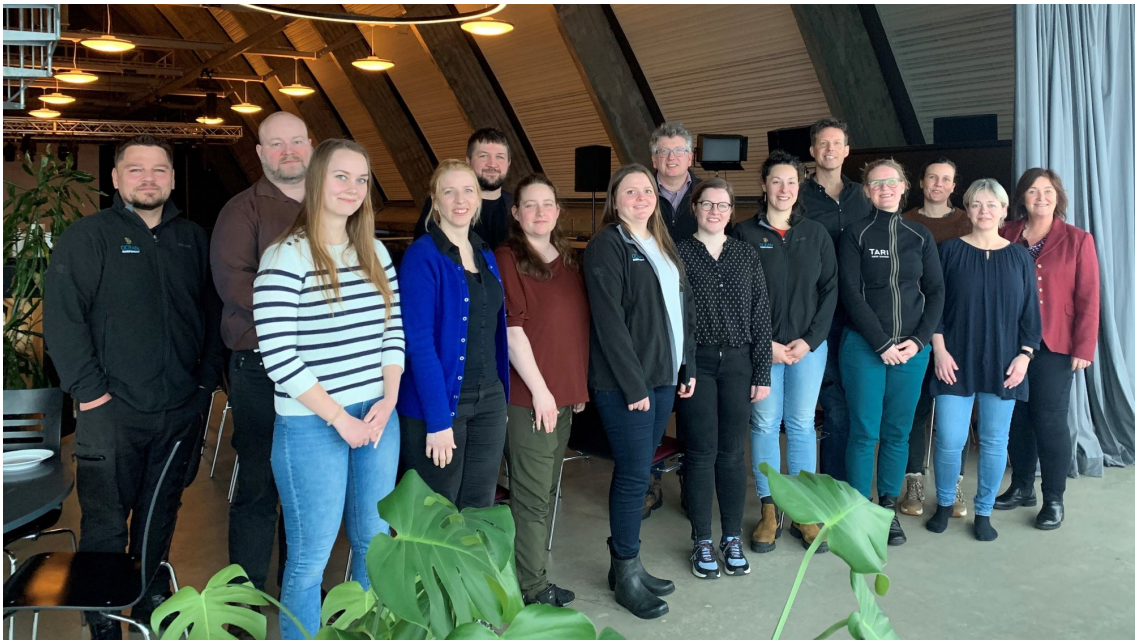

Figure 1.1.: Some of the workshop participants pictured in SALT, Suðuroy, on 15 March 2023.

Herein a short summary is given of each presentation, and presentation slides are attached where permission from the presenters was given. Additionally the key points from the panel discussion are included.

The program for the workshop, translated to English can be found in Table 1.1. The Faroese workshop flyer and the original workshop program can be found in Appendix A.

Table 1.1.: Workshop program translated to English

11:15	**Welcome** *Jóhanna Lava Køtlum, Fiskaaling*
11:20	**Management of algae cultivation, what is being done and what is missing?** Macroalgae cultivation and environmental management *Anni á Hædd, Ministry of Environment* Granting of licences for macroalgae cultivation in the Faroe Islands *Bárður Enni, Faroese Food and veterinary authority (FFVA)*
11:40	**Knowledge on the environmental conditions in Faroese fjords** Hydrography and biology in Faroese fjords *Gunnvør á Norði, Fiskaaling*
12:00	**Lunch**
13:00	**Environmental effects of macrofauna aquaculture** Environmental Impact Assessment, principles and monitoring + the goal of ASuReMacro *Birgitta Andreasen, Fiskaaling (Susse Wegeberg, Aarhus Universitet)* How can macroalgal cultivation affect marine ecosystems - Experiences from a Norwegian project *Kasper Hancke, Norwegian Institute of Water Research (NIVA)*
14:10	**Coffee break**
14:25	**Experiences in the industry including environmental considerations** Sustainable and resilient macroalgae cultivation on the Faroe Islands – knowledge and method building *Agnes Mols Mortensen, Tari Spf.* Lessons learned and future approaches on measuring impact on the marine ecosystem related to macroalgae cultivation *Ólavur Gregersen, Ocean Rainforest* Macroalgae cultivation in Norway. Today's status and future plans *Gunhild Borgersen, Norwegian Institute of Water Research (NIVA)*
15:10	**Panel discussion and questions**
15:35	**Workshop ends**

2. Presentation summaries

2.1. Welcome

Presenter: **Jóhanna Lava Køtlum**, *CEO, Fiskaaling*

Good morning, and welcome to this workshop hosted by Fiskaaling. Fiskaaling, also known as The Aquaculture Research Station of the Faroes, is a research company owned by the Faroese Government with the vision "Knowledge for sustainable aquaculture". We focus on producing and gathering knowledge that can serve as the foundation for developing a sustainable aquaculture industry, which is key to ensuring sustainability.

At Fiskaaling we are delighted with the establishment of this project *A sustainable and resilient macroalgal cultivation industry in the Nordic and Arctic region (ASuReMacro)*, the purpose of which is to be at the forefront in monitoring and estimating possible impact on the fjords.

What makes this project special is that we are now more or less at the cutting edge of a growing industry. This stands in contrast to the Faroese salmon farming industry, which began long before any monitoring systems were developed to assess the possible environmental impact of the industry. This position allows us to learn from past mistakes and shape a more sustainable future.

Bringing together the industry, authorities, policymakers, and researchers is an initiative to be leveraged for the benefit of the industry, society and sustainability.

I wish us all a good and constructive day, where we can exchange knowledge, insights, and ideas - which I'm very much looking forward to.

2.2. Management of algae cultivation, what is being done and what is missing

2.2.1. Macroalgae cultivation and environmental management

Presenter: **Anni á Hædd**, *Advisor, Ministry of Environment*

In the 1990'ies and early 2000, the Faroese Fish farming aquaculture took off and grew substantially with many fish farms randomly scattered in the fjords. The intensification of fish farming caused unseen challenges to both farmers and the regulatory regime. The battle against salmon diseases was lost and resulted in a major collapse of the industry. The collapse paved the way for a new beginning.

Slowly but surely farmers have spent the last 20 years rebuilding the fish farming industry to an extent previously unseen. To this end, the regulatory regime was updated by Parliament where the separation of fish farms in the fjords and disease prevention has been essential. The environmental regulations have not yet been updated correspondingly although the terms and conditions of the environmental approvals may be strengthened by administrative means. Consequently, lessons learned from fish farming may be transferred to the management scheme and regulatory regime for macroalgae cultivation before pilot projects and experimental production turns into solid and sustainable industry.

Today the Faroese macroalgae farming activities are somewhere between pilot projects led by enthusiastic pioneers and an emerging industry. There is little competition amongst farmers or sea areas. Currently, there is no specific regulatory regime comprising macroalgal farming and thus it is regulated by general rules in the fish farming act and the marine environmental protection act including requirements of Environmental Impact Assessment (EIA).

As the macroalgae cultivation moves into industrial scale, the call from different stakeholders for Governmental action will most likely intensify. There will be a need to provide a balanced regulatory regime, where environmental monitoring is key to identify positive and negative effects of intensive concentrations of macroalgae aquacultures in Faroese sea waters. The interaction with other land and sea-based activities should also be identified and considered.

In addition, marine spatial planning will likely become more important as there seems to be no limits for the multiple use of the ocean. Marine spatial planning may be the instrument needed to deal with different and sometimes conflicting interests that push forward to get access to a specific sea area.

The protection of the marine environment and nature earns principal attention as it is the very foundation for sustainable food production from the ocean. Cooperation amongst private and public stakeholders will be necessary to expand our environmental insight into the marine environment. We need to join our forces to collect and share knowledge of the marine environment in the Nordic countries. For a small country like the Faroe Islands, this is considered paramount to protect our marine environment and to maintain a sustainable use of our marine resources to the benefit of society.

Presentation slides are available in Appendix B.

2.2.2. Granting of licences for macroalgal cultivation in the Faroe Islands

Presenter: **Bárður Enni**, *CEO, Faroese Food and Veterinary Authority (FFVA)*

Salmon farming started in the 1970ies. At that time the policy regarding the fish farming industry was to support rural areas and that individual fish farms should be small.

In 1985 there were 65 fish farming locations operated by ~50 companies that produced 3000 tonnes in total. Thus, there were 3 - 4 farmers in each fjord and there were no veterinary regulations or monitoring.

In the early 2000 the fish farming industry almost collapsed due to infectious salmon anaemia (ISA) outbreaks. As a result of these outbreaks strict veterinary regulations were established in 2003 to prevent disease transfer.

The production of farmed fish has increased considerably since the crises and today there are 23 sites operated by three companies that produce 85000 tonnes in total.

Up until 2018 the regulation implied that there was no space for farming of other species than salmon. Regulations were changed in 2018 to accommodate the possibility of farming multiple species in a single fjord, the legislation was changed for six locations (Kaldbaksfjørð, Eystan fyri Nólsoynna, Gøtuvík, Skálafjørð, Funningsfjørð, and Famjin). This change was motivated by the many applications received to farm blue mussels and seaweed that had to be rejected due to the aquaculture regulation from 2003. The idea behind the new regulation is that it is now possible to farm several species in one fjord, *e.g.*, farming on land + salmon farming + seaweed + blue mussels.

However, the lessons learned from the salmon farming industry have made the authorities very cautious with new cultures. Thus, there are only four licences issued for seaweed farming to begin with.

The process of issuing licences started with announcements in the papers, that it was now possible for anyone to apply for the four licences for macroalgae farming. In the announcement the requirements for the applications were also dictated.

The applicant should provide information on the financing, planned production, planned use of the seaweed etc. and also where on the fjord the applicant wished to place the farm.

The treated applications were then sent out for hearing at the relevant stakeholders, such as the local municipality, the environmental agency, the food and veterinary agency, the local fish farming company and lobster fishermen.

Current cultivation permits are listed on the website: www.foroyakort.fo

2.3. Knowledge on the environmental conditions in Faroese fjords

2.3.1. Hydrography and biology in Faroese fjords

Presenter: **Gunnvør á Norði**, *Senior Researcher, Fiskaaling*

The coastal areas in the Faroe Islands can roughly be divided in two, when it comes to the ecological state; the mixed shelf water and the stratified fjords with estuarine circulation. In the mixed shelf water the tidal currents are strong and the water masses are vertically mixed from surface to bottom. This implies that there is seldom nitrogen depletion and that effluents from anthropogenic activity are quickly dispersed over wide areas. In the fjords, nitrate depletion is regularly occurring in the upper water masses during the growth season, but the stratification is so weak that there is frequent up welling of nutrients. The annual microalgae production in Faroese fjords is 2 - 3 times higher than in neighbouring regions due to the frequent nutrient up welling.

The benthic macrofauna diversity in the Faroe Islands is well investigated in connection to fish farm monitoring and a classification system for evaluation of environmental state is established.

The Faroese shore is quite steep and the total area of *Laminaria* kelp forests is estimated to be 275 km^2. The zone where *Laminaria* grows is considerably wider in exposed areas than in sheltered areas such as fjords. In fjords it is often the substrate that limits the growth area.

There is little local knowledge on the importance of seaweed as nursing areas for commercial fish stocks.

In general, there are many knowledge gaps, and one of the most important gaps is the lack of national monitoring in consensus of the Water Framework Directive and thus lack of long time series in fjords.

Presentation slides are available in Appendix C.

2.4. Environmental effects of macroalgal cultivation

2.4.1. Environmental Impact Assessments, principles and monitoring + The goal of ASuReMacro

Presenter: **Birgitta Andreassen**, *ASureMacro Project Leader, Researcher, Fiskaaling*

The project *A Sustainable and resilient macroalgal cultivation industry in the Nordic and Arctic Region (ASuReMacro)* is funded by the Nordic Council of Ministers. The project commenced in December of 2022 and will run for one year. The project is led by Fiskaaling with partners from Aarhus University, The Norwegian Institute for Water Research (NIVA) and Tari Spf.

ASuReMacro, aims to build the knowledge foundation to develop a sustainable and resilient macroalgal cultivation industry in the Nordic and Arctic region. ASuReMacro will, through collaboration with the Norwegian KELPPRO project, define which parameters should be included in a baseline studies programme for creating the base for monitoring and environmental assessments to adjust and maintain a sustainable and resilient macroalgal cultivation in Faroese fjords. ASuReMacro also aims to develop an implementation plan for the baseline studies programme.

Environmental Impact Assessment (EIA)

The overarching purpose of an EIA is to outline the environmental consequences of a project for the proponent and authorities, the public and eventually decision makers (Karvinen and Rantakallio 2019).

The exact framework of an EIA varies from country to country, but in general the framework can be outlined in eight steps.

1. Screening
2. Scoping
3. Baseline Study
4. Impact Assessment
5. Mitigation Measures
6. Reporting and Reviewing
7. Decision Making

8. Monitoring

This workshop is part of the first work package (WP1) of the project that will feed directly into the WP2 in which a Baselines Studies Programme report is produced that will include five of the eight steps of an EIA, namely scoping, baseline study, impact assessment, mitigation measures, and some recommendations for environmental monitoring. The report will focus on the points relevant to macroalgae cultivation in Faroese fjords. WP3 will then develop an implementation plan of this.

Presentation slides are available in Appendix D.

2.4.2. How can macroalgal cultivation affect marine ecosystems - Experiences from a Norwegian project

Presenter: **Kasper Hancke**, *Senior Researcher, Norwegian Institute for Water Research (NIVA)*

The research project *Kelp industrial production: Potential impacts on coastal ecosystems (KELPPRO)* was funded by the Norwegian Research Council from 2017 to 2020, and was the first of its kind in Norway. The project was led by Kasper Hancke at the Norwegian Institute for Water Research, and encompassed field investigations, laboratory experiments, and numerical modelling to investigate environmental impacts of kelp cultivation on marine ecosystems in open water bodies and seabed habitats, with the aim to evaluate potential positive and negative effects on the marine environment. In addition, an evaluation of kelp farms potential contribution to the spread of alien or endangered species and/or genetic material was completed. The motivation behind the KELPPRO project was the recent development in the seaweed farming industry and the growing interest in expanding kelp cultivation globally and in Norway. With this, a list of emerging questions arose on potential positive and negative effects on marine environments.

A fundamental question was *"Is it possible to create a sustainable seaweed aquaculture?"* In short, the main results from KELPPRO argues for answering *"yes"* to this question, with keywords being 1) the development of the industry needs to actively take nature-based solution into account and and 2) the society needs to secure an efficient and knowledge-based management plan scaled to the growing industry.

With a global seaweed industry harvesting >32 mill. tonnes annually (FAO 2022) and a fast-expanding Nordic industry, focus on environmental sustainability is essential. Fundamentally, kelp farms function ecologically significantly different from fish farms. In sum, kelp farms have a negative net emission of nutrients and CO_2 while fish farms have a positive net emission of nutrients and CO_2 (see Figure 2.1).

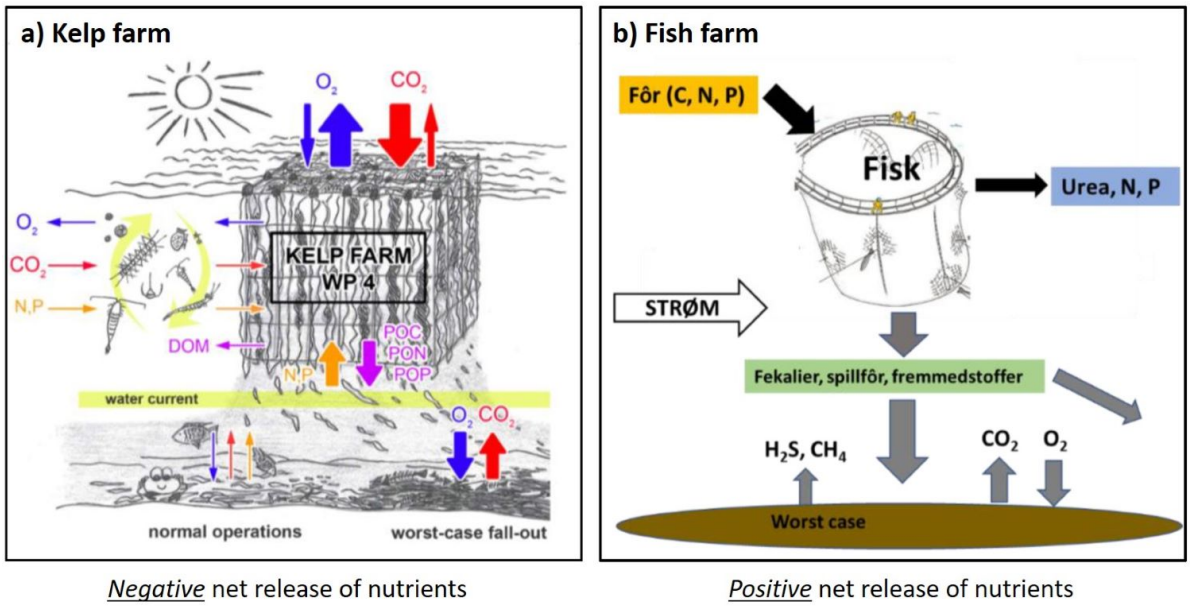

Figure 2.1.: Sketch showing differences between kelp and fish farming. a) Kelp farms are taking up inorganic nitrogen (N), phosphorus (P) and carbon dioxide (CO_2) from the sea for the synthesis of organic matter (kelp biomass), using energy from sunlight. During growth, kelp produce oxygen (O_2) and simultaneously export particulate organic matter carbon (POC), nitrogen (PON) and phosphorus (POP), which consequently is leading to that some of the taken up nutrients are returned to the water masses. Kelp cultivation plants thus have a negative net emission of nutrients and CO_2. b) Fish farms in contrast, add feed during operations containing carbon (C), N and P. A proportion of these nutrients are released into the surrounding environment either as feed that is not eaten or through faeces which sinks under the facilities. Fish farms thus have a positive net emission of nutrients and CO_2. *Image adapted from Hancke et al. (2021).*

Kelp farms potentially impact marine ecosystems through physical, biological, and biogeochemical processes, all with following environmental trade-offs depending on the size and harvested yield of the farm. Large-scale kelp farms will physically alter water currents, absorb sunlight, and provide physical hideaways and colonisation structure for fauna. Performing photosynthesis, kelp take up nutrients and CO_2, and export oxygen and organic matter (detaching leaves) to its surroundings during growth. This leads to positive effects such as reduced eutrophication, reduced ocean acidification, CO_2 drawdown, oxygen production, increased primary production, and stimulated biodiversity. On the contrary, the same processes can lead to reduced light availability, depletion of nutrient availability, deposition of organic matter on the seafloor, that again can cause poor environmental conditions, oxygen deficiency, change in biodiversity, and spreading of unwanted species, genetic material and diseases. A schematic overview is given in Figure 2.2.

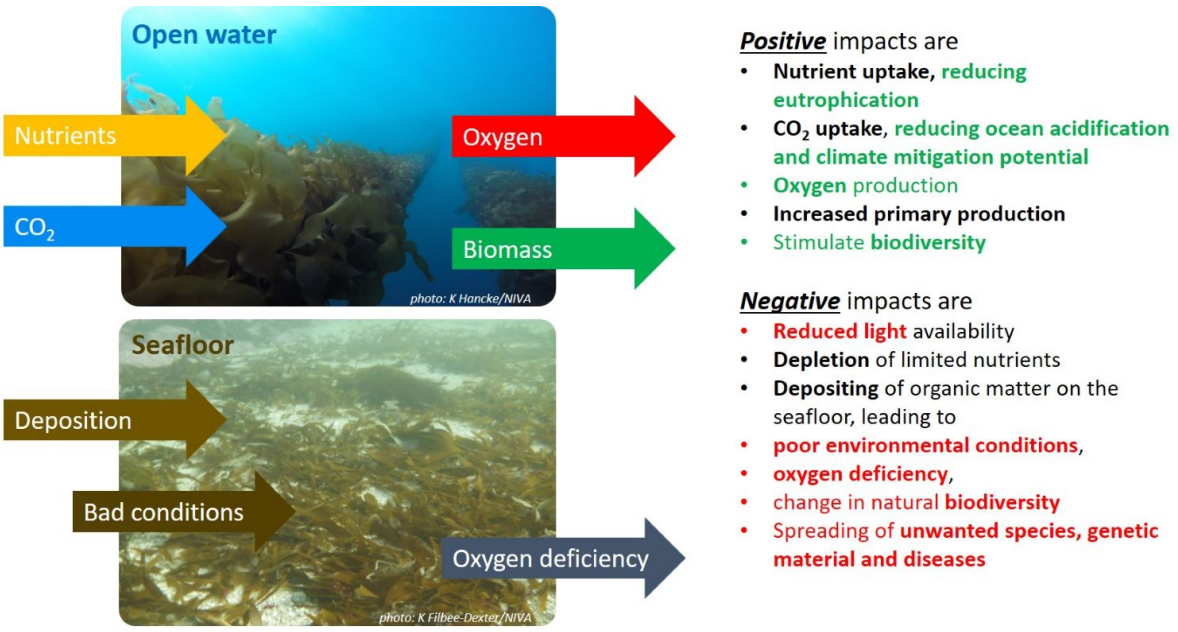

Figure 2.2.: An overview of potential environmental impacts of extensive seaweed cultivation.

The KELPPRO project produced a number of papers, talks, and outreach activities, in addition to a summary report (Hancke et al. 2021) that highlights major conclusions from the research and contains a set of recommendations towards formulating a management plan for environmental impact assessments for kelp cultivation.

Presentation slides are available in Appendix E.

2.5. Experiences in the industry including environmental considerations

2.5.1. Sustainable and resilient macroalgae cultivation on the Faroe Islands - knowledge and method building

Presenter: **Agnes Mols Mortensen**, *CEO, Tari Spf.*

TARI produces high quality seaweed for food (end products and ingredient products), and the company also produces AkvaNest (a cleaner fish shelter) for the salmon aquaculture industry. TARI holds two cultivation licences; a land based hatchery licence and a fjord based on growth licence. The company's cultivation licence includes five different macroalgal species. Developing sustainable and resilient production methods and producing high quality biomass is a focus area at TARI. It is important to use the available natural area to produce the best possible quality of seaweed biomass and be very careful not to over exploit the area. Building a knowledge base about the local natural area is fundamental to running a sustainable and resilient production, thus much effort is being put into procuring this knowledge. Some of the sustainability factors that TARI is working with are:

- monitoring nutrient fluctuations on the farm and in the hatchery
- monitoring bacteria concentrations of the farm
- studying the natural flora and fauna in the local natural area surrounding the farm
- studying the population genetic structure of seaweed species that are relevant to culture
- running the hatchery on renewable energy
- diversifying the cultivation by including more species in the production

As seaweed farming is increasing in size sustainable and resilient cultivation methods will become crucial.

Presentation slides are available in Appendix F.

2.5.2. Lessons learned and future approaches on measuring impact on the marine ecosystem related to macroalgae cultivation

Presenter: **Ólavur Gregersen**, *CEO, Ocean Rainforest*

Ocean Rainforest was established in 2007. The first seeded lines were deployed in 2013 and the first licence to farm macroalgae was obtained in 2020. It is only during the recent 2 - 3 years that the company has started to upscale its production.

Today the company operates in the Faroe Islands, Iceland, Norway, Denmark, and the USA. The market is business to business: ~40 % fermented, ~40 % food and feed ingredients, and the rest is extraction of fucoidan.

There are many steps in the establishment of a cultivation site.

- Feasibility study; analysis of hydrodynamics, temperature, depth, nutrients etc.
- Finite Element Analysis
- Front end engineering; Design of rig to the actual site
- Permit processing (The Faroe Islands is one of the best places regarding licence processing)
- Final rig configuration
- Deployment
- Operation (seeding and harvesting)
- Monitoring and maintenance.

The company is involved in various EU projects that also address the environment (*e.g.*, SEAMARK and AquaVitae). In general, the results show that there are no negative impacts on the marine ecosystem. On the contrary there is a potential positive impact on marine biodiversity and bio stimulants.

Presentation slides are available in Appendix G.

2.5.3. Macroalgae cultivation in Norway. Today's status and future plans

Presenter: **Gunhild Borgersen**, *Researcher, Norwegian Institute for Water Research (NIVA)*

Norway has a long tradition of harvesting seaweed on the shores, but cultivating kelp is a relatively new industry in Norway. The first licence for kelp cultivation was granted in 2014, and there are now around 100 locations with permission to grow cultivated kelp at sea. The production has increased somewhat since the beginning, from approximately 50 tonnes in 2015 to 250 tonnes in 2021, but is still modest. It is mainly sugar kelp and winged kelp (*Saccharina latissima* and *Alaria esculenta* respectively) that are produced.

Globally, cultivation of kelp has doubled in the last 10 years, and for Norway it is predicted that 20 million tonnes per year can be produced by 2050 (Olafsen et al. 2012). This will require much larger cultivation facilities than what exists today, and a need for cultivation areas in the sea between 2000 and 3000 km^2. This raises the question of how to obtain such a high production in a sustainable and environmentally friendly way, and at the same time profitable. The environmental conditions are suitable for kelp cultivation along the entire Norwegian coast, but modelling shows that the potential for kelp production is highest offshore. The industry in Norway is now looking at the possibility of growing kelp further from the coast than they do today. The research project Seaweed Carbon Solutions (lead by SINTEF OCEAN in Norway) aims to build an offshore kelp farm for carbon capture. A smaller pilot farm (1 km^2) is planned for an exposed site on the west coast of Norway. Although the pilot farm is small compared to the large-scale industrialised facilities that are planned later in the project, it will still be the largest cultivation facility in Norway, and produce 3 times as much biomass as was produced in the whole of Norway in 2021 (250 tonnes). Two methods for carbon capture and storage will be tested and evaluated: the production of biochar for soil improvement on land, and the sinking of kelp biomass into the deep sea.

Another research project (GP SEAWEED, also led by SINTEF OCEAN with multiple partners) aims to strengthen the kelp industry in Norway by developing end products that can be brought straight to the market and thus increase the demand for cultivated kelp. The project focuses on fermented kelp as a food product, kelp as an ingredient in animal feed, in bioplastics and other materials for packaging, and the development of biochar. The entire value chain must be sustainable and environmentally friendly, and is also assumed to have positive climate effects because the kelp replaces other ingredients that have higher emissions.

NIVA will study the environmental effects of large-scale (offshore) kelp cultivation. We will carry out baseline studies at the location before cultivation starts, and can then gradually investigate any effects of the pilot farm and later of the large industrial scale farm. We will focus on effects on the seabed and benthic fauna, and estimate the amount of carbon emitted from the kelp farm by measuring eDNA from kelp in the sediment. We will also study disease on cultivated kelp, which represents a large knowledge gap. Disease outbreaks in a kelp farm may lead to pathogens spreading to the natural kelp forests nearby, which could cause irreversible ecological effects and damage. Finally, the kelp farm may function as an artificial habitat and possibly contribute to increased biodiversity, but also the spread of alien species.

Presentation slides are available in Appendix H.

3. Panel discussion and questions

Interactions between fish farming and macroalgae:

It is often postulated that seaweed can act as a reservoir for diseases that affect the fish farming industry. The FFVA addresses this possible issue by moving slowly forward with issuing licences for macroalgae cultivation.

Future licences in Faroese waters:

In the near future, a licence for blue mussels will be issued, but regarding seaweed it will probably take some time before more licences are issued as this first round with the four licences is not yet finalised. In the long term there will probably also be offshore licences but the level of conflicting interests might be even higher offshore than it is in the fjords. In order to significantly upscale the macroalgae aquaculture in the Faroes, it will be necessary to move offshore due to spatial constraints.

Environmental data:

Today there is no authority that collects and organises environmental data and there is no basic environmental monitoring, which is required in all EU countries.

With today's political structure, the gathering of data falls between areas and there is no centre for gathering data. There has been too little focus on data and environment, but hopefully this will change now that there is an international wave and requirements regarding sustainability.

The most emerging threats and monitoring needs in seaweed farming:

From the studies conducted, there seems to be little benthic impact from seaweed farming, even when simulating total breakdown, where an entire seaweed farm sinks to the seabed. Thus, it does not seem that the major environmental concern is similar to the concern of other farmed species such as *Bivalvia* and fish. The workshop participants considered the major environmental concern to be unforeseen disease outbreaks and loss of genetic diversity and biodiversity in the natural seaweed. Both issues can have an influence on the ecosystem functioning as seaweed forests that are important habitats for marine life in general.

Experiences from seaweed farmers is that during autumn there can be severe grazing on the biomass by the snail Lacuna vincta and if the seaweed farm is close to a fish farm *Caprella mutica* can be highly abundant in the seaweed biomass, but with sufficient distance that is not a problem.

However, with timely harvesting of the cultivated seaweed biomass in the spring and early summer the problem with *L. vincta* and *C. mutica* is eradicated.

Measures to prevent disease outbreaks:

In the salmon farming industry, there is a mandatory fallowing between farming cycles at fjord level, and also special regulations in the case of an outbreak. Similar considerations for the macroalgal industry were discussed, and this is something that the food and veterinary authority is experienced in.

If similar regulations are to be implemented in the macroalgal industry there is a need for the farmers to have enough areas in order to sustain a stable production even though some areas need to lay fallow.

Parasites are generally quite species specific so polyculture could be considered when upscaling macroalgae cultivation as a strategy to develop a resilient industry and minimise potential disease outbreaks.

Discussion of farming methods:

Both brown algal species, *Alaria esculenta* and *Saccharina latissima* that are cultivated in the Faroe Islands, have the ability to take up nitrate and store it until it can be used for growth during the spring season when there is enough light. To alter the growing season could prove more difficult than just controlling nutrients and light conditions. That line of thought would also be in opposition to developing a sustainable and resilient macroalgal cultivation industry with minimum impact on the natural area.

Both farming companies in the Faroe Islands state that the key to success is to farm within the environmental settings instead of trying to alter the conditions. The growth potential of macroalgal farming is considerably larger in the North Atlantic than e.g. the North sea.

The two seaweed farming companies in the Faroe Islands have different strategies. One uses several partial harvests where the lines are deployed continuously for 2 - 3 years. The first year there is a monoculture of the seeded species and subsequent years there is a mixture of the seeded species and species that have attached naturally. The first harvest has the finest quality while the autumn harvest is not that clean but still good for extraction of bioactive compounds. The seaweed disappears during winter but can grow until October. Grazing by the snail is observed in late summer but disappears during August.

The other company seeds and harvests the entire lines annually. They produce high quality products for human consumption that are harvested before biofouling occurs, and aim to widen the production cycle by farming multiple species. They also produce shelters for cleaner fish (AkvaNest) that are not harvested for food but are a potential resource for biogas production.

Large scale macroalgal cultivation and carbon credits:

There is a huge interest in macroalgal cultivation in regards to carbon credits and capital strong investors are interested to invest in macroalgal farming companies. Thus the pressure on the authorities to release macroalgal cultivation licences can increase considerably and it is important that the authorities have a strategy that ensures a sustainable and resilient macroalgal industry.

In Norway there is a project, Seaweed Carbon Solutions, where a large scale cultivation rig will be established and monitored in order to investigate the environmental effects of large scale cultivation. Both NIVA and Ocean Rainforest are involved in the project.

Future projections:

Today's macroalgal cultivation in Europe is not an established industry. It is based on a few pioneers and can be compared to the salmon farming industry in the 1980ies.

Where macroalgal farming will be in 10 years depends on the market, *e.g.* if there will be a market in feed for milk cows to reduce the carbon footprint there is a large growth potential. However, that also means that the producers must be able to scale up and have a reliable supply.

As it is today the standards for fish farming gear to be deployed at sea are also used for macroalgal rigs, but today's gear for macroalgal cultivation does not meet the requirements as the demands for solid macroalgal equipment is not necessarily the same as for fish farming. When the gear does not meet the applicable standards, it cannot be insured, and when it can not be insured there are no investors. So, there is a need for research within macroalgal gear and standards.

There is a limited area for nearshore farming and in order to upscale considerably, the farms will need to move offshore. The experience is also that the yield is higher in more exposed areas. If moving offshore is successful the macroalgal farming potential in the Faroe Islands is huge.

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Olafsen, Trude, Ulf Winther, Yngvar Olsen, and Jorunn Skjermo. 2012. “Verdiskapning basert på producktive hav i 2050.” Norway: Det Kongelige Norske Videnskabers Selskab (DKNVS) og Norges Tekniske Vitenskapsakademi (NTVA).

5. Appendices

A) Faroese workshop flyer and original program

Presentation Slides:

B) Macroalgae cultivation and environmental management

C) Hydrography and biology in Faroese fjords

D) Environmental Impact Assessments, principles and monitoring + The goal of ASuReMacro

E) How can macroalgal cultivation affect marine ecosystems - Experiences from a Norwegian project

F) Sustainable and resilient macroalgae cultivation on the Faroe Islands - knowledge and method building

G) Lessons learned and future approaches on measuring impact on the marine ecosystem related to macroalgae cultivation

H) Macroalgae cultivation in Norway. Today's status and future plans

A. Faroese workshop flyer and original program

Figure 5.1.: Workshop flyer in Faroese

Table 5.1.: Workshop program in Danish

11:15	**Velkommen**
	Jóhanna Lava Køtlum, Fiskaaling
11:20	**Forvaltning af algedyrkning - hvad bliver gjort og hvad mangler?**
	Tangopdræt og miljøforvaltning
	Anni á Hædd, Umhvørvismálaráðið
	Tildeling af licenser til opdræt af tang på Færøerne
	Bárður Enni, Heilsufrøðiliga Starvsstovan
11:40	**Økologisk forståelse om færøske fjorde**
	Hydrografiske og biologiske omstændigheder på de færøske fjorde
	Gunnvør á Norði, Fiskaaling
12:00	**Frokost**
13:00	**Miljøeffekter**
	Miljøvurdering, generelle principper og overvågning + Formål med ASuReMacro
	Birgitta Andreasen, Fiskaaling (Susse Wegeberg, Aarhus Universitet)
	Hvordan kan tangdyrkning påvirke havmiljøet - erfaringer fra et norsk projekt
	Kasper Hancke, Norsk Institutt for Vannforskning (NIVA)
14:10	**Kaffepause**
14:25	**Erfaringer fra industrien herunder miljøovervejelser**
	Bæredygtig og resilient makroalgeproduktion på Færøerne - opbygning af viden og metoder
	Agnes Mols Mortensen, Tari Spf.
	Lessons learnt and future approaches on measuring impact on the marine ecosystem related to macroalgae cultivation
	Ólavur Gregersen, Ocean Rainforest
	Tare/tang dyrking i Norge: status i dag og planene fremover
	Gunhild Borgersen, Norsk Institutt for Vannforskning (NIVA)
15:10	**Paneldiskussion og spørgsmål fra publikum**
15:35	**Workshoppen slutter**

B. Macroalgae cultivation and environmental management

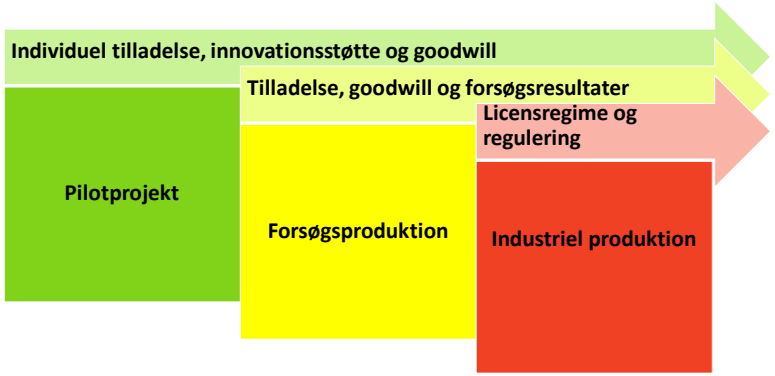
Presenter: **Anni á Hædd**, *Advisor, Ministry of Environment*

Tangopdræt og miljøforvaltning



Anni á Hædd, jur. rådgiver
Umhvørvismálaráðið / Miljøministeriet

Nye næringsformer og reguleringsmæssige udfordringer



Tangopdræt og miljøforvaltning i Færøerne

- **Høringsudtalelse fra US til HS ang. opdrætslicens**
- Miljøbeskyttelseslov
  - Almindelige regler land, vand og søterritorium
  - Liste F: Virksomheder, der producerer "fiskeprodukter"
  - Liste J: "Fiskeopdræt"
- Havmiljøbeskyttelseslov
  - Forebygge og mindske anden forurening af havet, § 20 [Bekendtgørelseshjemmel]
  - Miljøkonsekvensvurdering, § 21 [projekter & virksomhed over bagatelgrænse]
- Naturbeskyttelseslov – lovforslag fremlagt
  - På land, i vand og FO søterritorium
- Arealtildeling og regulering
  - Landarealer - byplanlægningslov
  - Havområder - ingen arealplanlægningslov

Miljøkonsekvensvurdering, § 21 i HUL

- Projekter og virksomhed på havet, som påvirker natur og miljø i væsentlig grad, kan ikke påbegyndes uden godkendelse.
  - Vurdere påvirkning
  - Vurdere væsentlighedsgraden af påvirkningen
- Vurdering af konsekvenser kræver viden om natur og miljø i området
  - Afgrænse området og dets radius
  - Undersøge natur og miljø på havbunden, i vandsøjlen og på havet (Baseline)
  - Samspil med anden påvirkning i samme område
  - Andet?
- Offentlig høring af konsekvensudredning
  - Behandling af indsigelser
- Efterfølgende miljøovervågning

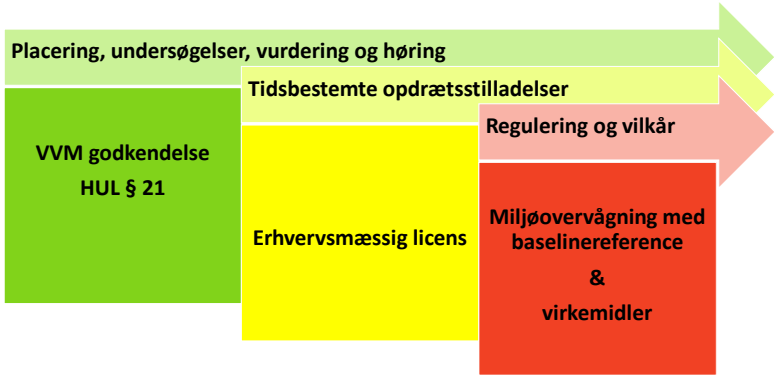
Mangelfuldt vidensgrundlag

- Lange, robuste liner udsættes i fjordområder
- Tangen vokser og liner synker ned mod havbunden
- Store koncentrationer af tang
- Tangen skygger for ovenlys
- Tangen tiltrækker visse dyr
- Udskiller tangen stoffer
- Bundfald
- Sejlads og transport ved høstning af tang

Samspillet med anden aktivitet i området

- Erhvervsaktivitet så som sejlads, lakseopdræt og fiskeri
- Fritidsaktiviteter, så som sejlads, fritidsfiskeri, roning, kajak, havsvømning m.v.
- Kommunal spildevandsudledning, procesvand fra landbaserede anlæg, gødningsstoffer fra landbruget mv.

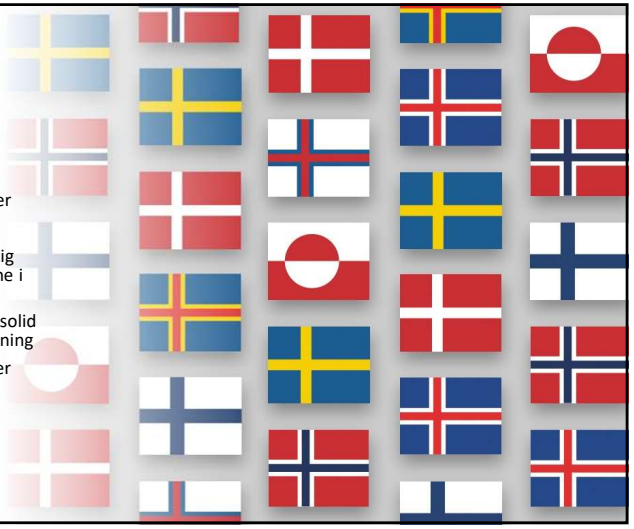
Ideel miljøforvaltning af opdrætslicenser



Samarbejde og sameksistens

- Havet er vores spisekammer
- Mange interessenter
- Fælles ansvar for bæredygtig forvaltning af havområderne i Norden
- Nordisk samarbejde sikrer solid vidensopbygning og -spredning
- Vi deltager og bidrager efter evne

- Lykke til med projektet ☺



C. Hydrography and biology in Faroese fjords

Presenter: **Gunnvør á Norði**, *Senior Researcher, Fiskaaling*

Fiskaaling
Aquaculture Research Station of the Faroes

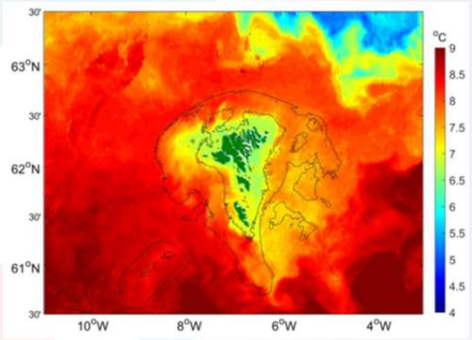
Hydrografiske og biologiske omstændigheder på de færøske fjorde

Gunnvør á Norði

Taraaling á føroysku firðunum – tørvurin á umhvørvismeting og eftiransing

15. mars 2023

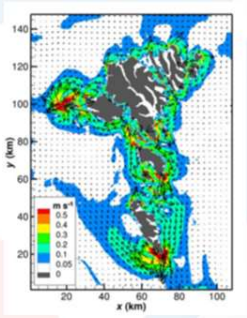
The Faroe shelf



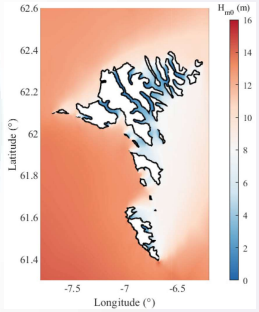
- Persistent front at 100 – 150 m depth separating the shelf water from the open ocean
- Stable temperatures and salinity
- Vertically mixed watermasses
- The shelf sustains a neritic ecosystem that differs from the oceanic environment

Source Havstovan, available in: ICES. 2023. Workshop on the Faroes Ecoregion Aquaculture Overview (WKFaroesAO). ICES Scientific Reports. 5:28. 87 pp. https://doi.org/10.17895/ices.pub.21551541

Currents and waves in near shore environments



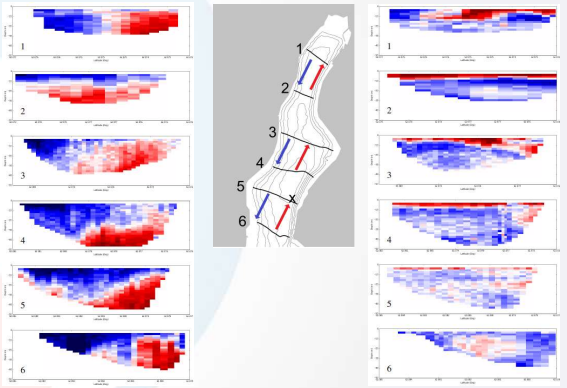
Kragesteen et al. 2018



Joensen et al. 2021

- Strong tidal currents in most straits
- Considerably weaker currents in fjords
- Many areas exposed to ocean swells

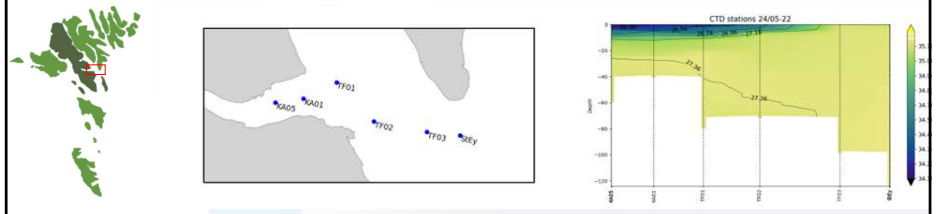
Currents in Fjords



- Estuarine circulation Influenced by wind and Coriolis
- Circulation can be reversed due to winds

Source Fiskaaling , available in: ICES. 2023. ICES Scientific Reports. 5:28. 87 pp.

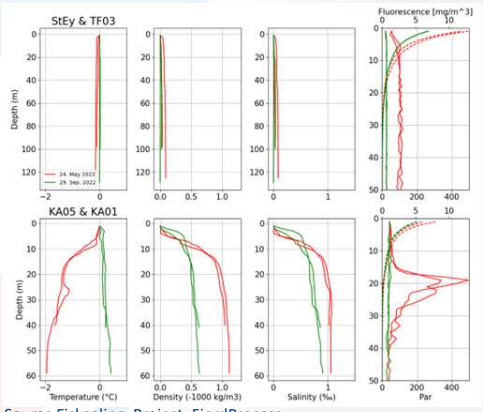
Stratification

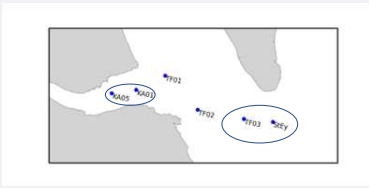


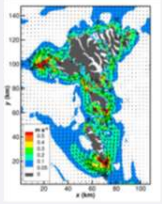
Source Fiskaaling, Project: FjordProcess

Year round stratification in fjords
Vertically mixed water masses in areas with tidal currents

Stratification





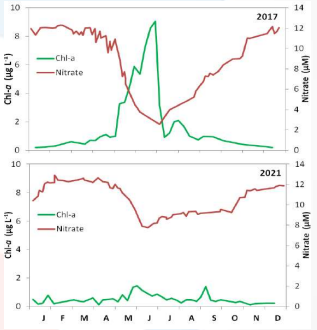


Faroese stratified areas: Generally small temperature and salinity differences with depth

Source Fiskaaling, Project: FjordProcess

Nutrient availability

Faroe shelf



Source Havstovan,
available in: ICES. 2023 WKFaroesAO

Fjords

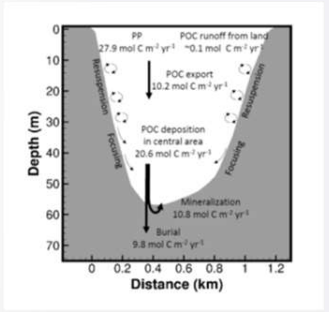
Stratification and nutrient depletion during summer but frequent nutrient upwelling

Østerø et al. 2021 Fiskaaling rit 2022-03

Microalgae production

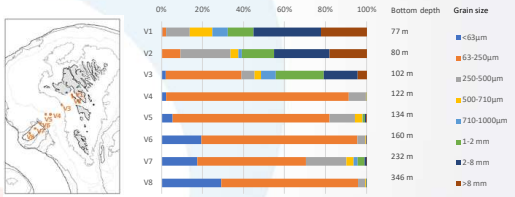
Annual microalgae production in Faroese fjords ~335 gC m^{-2} y^{-1}
2 -3 times higher than in neighnouring regions (Gaard et al. 2011)

ICES. 2023 WKFaroesAO

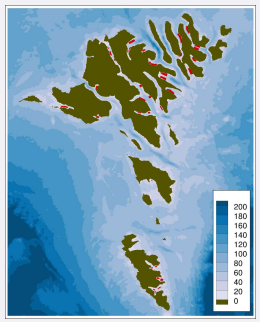


á Norði et al. 2018

Bathymetry and sediment



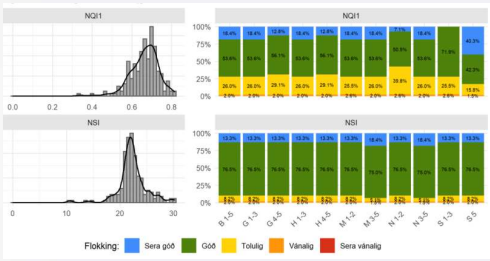
ICES. 2023. ICES Scientific Reports. 5:28. 87 pp.



Steep slopes with a flat muddy base.
Maximum depth in fjords ~40 – 100m Deeper fjords in the northern region

Benthic macrofauna

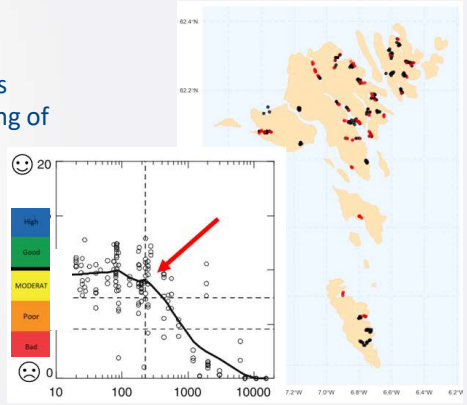
- Macrofauna samples from fish farming monitoring
- 196 reference samples
- Compared to ASC, GB, DK, SE, NO
- Macrofauna diversity comparable to NO



Mortensen et al. 2020 Fiskaaling rit 2020-16

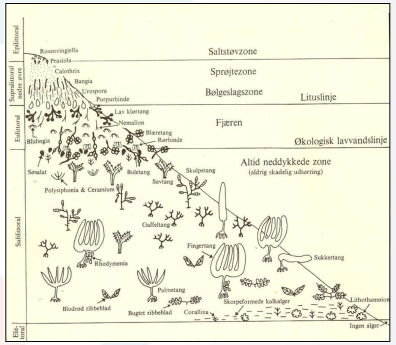
Benthic macrofauna classification system for Faroese fjords

- Water framework directive
- Based on macrofauna samples from environmental monitoring of fish farms
- 741 samples
  - Environmental agency
  - ASC-Aquaculture Stewardship Council
- Zn as pressure gradient
- Multi-metric index NQI



Mortensen et al. 2021 Fiskaaling rit 2021-10

Seaweed zonation



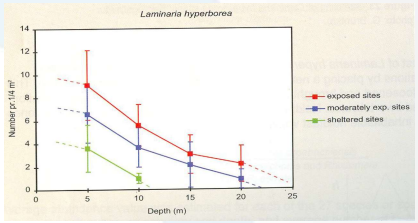
Substrate

Out drying

Competition

Light

Seaweed growth and wave exposure



Bruntse et al. 1999

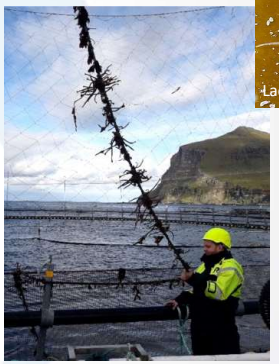
TABLE 1 | Predicted kelp forest area (km²) of the genera *Laminaria* and *Saccharina* per Nordic country or region.

Country/region	*Laminaria*	*Saccharina*
Norway	6797 (14486)	1303 (1303)
Svalbard	0 (464)	172 (850)
Denmark	567 (8120)	1 (21)
Greenland	42 (53)	834 (1251)
Iceland	1649 (4612)	54 (54)
Faroe Islands	275 (1631)	0 (0)
Sweden	36 (36)	21 (21)
Finland	0 (0)	0 (0)
Total	9366 (29402)	2385 (3500)

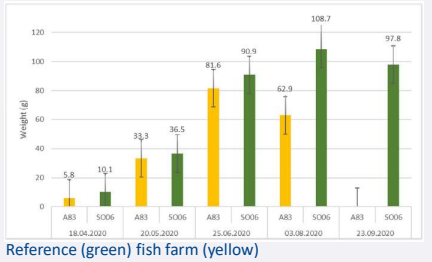
Number in parentheses include predictions in grid cells north of the northernmost observation or deeper than the deepest observation, or where the substrate is classified as soft bottom (for Denmark), i.e., predictions shown in light blue in ***Figure 3****.*

Kvile et al. 2022

Seaweed grazing



23 September 2021, reference (left) fish farm (right)



Reference (green) fish farm (yellow)

Schlund 2022

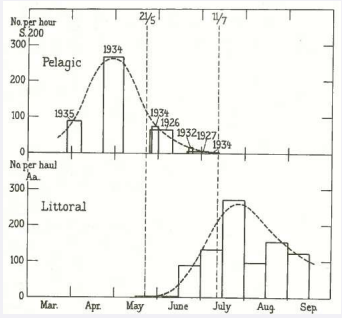
Seaweed as nursing areas

Few investigations

Bertelsen 1942
Investigations on the youngest age groups of saithe

Migrate to coastal areas in June

Ongoing pilot project
"Taraskógir sum uppvakstrarøki"
Havstovan, Tari, Fiskaaling



Knowledge gaps

	Knowledge gaps and data needs
Collected data	Making data FAIR, especially from old studies.
Time series in fjords	National seabed monitoring program in consensus to the Water Framework directive National monitoring of water parameters in fjords
Modelling	Hydrodynamic models (upcoming) Particle tracking models (on the way) Ecosystem models (Pelagic model will be generated in the project FjordProcess)
Seaweed	Mapping of the natural occurrence Epiphytes, epifauna and associated fish (some info in Brunte et al. 1999 and new project addresses this)

D. Environmental Impact Assessments, principles and monitoring + The goal of ASuReMacro

Presenter: **Birgitta Andreasen**, *ASuReMacro Project Leader, Researcher, Fiskaaling*

Miljøvurderinger:
generelle principper og monitering
+ formål med ASuReMacro

Susse Wegeberg (AU) og Birgitta Andreasen (FA)*

AARHUS UNIVERSITET Fiskaaling

Agenda

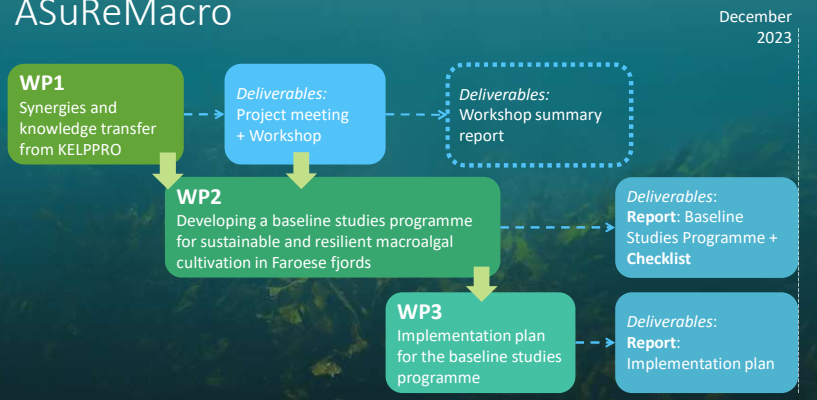
- The ASuReMacro project
- Environmental Impact Assessment (EIA)
  - The general framework
- Baseline Studies Progamme

ASuReMacro

A Sustainable and **re**silient **macro**algal cultivation industry in the Nordic and Arctic region

- funded by the Nordic Council of Ministers
- Started Dec 2022 – finishes Dec 2023
- Partners from:
  - Fiskaaling
  - Aarhus University
  - Norsk Institutt for Vannforskning
  - Tari Spf.

ASuReMacro



Environmental Impact Assessment (EIA)

"The overarching purpose of an Environmental Impact Assessment (EIA) is to outline the environmental consequences of a project for the proponent and authorities, the public and eventually decision makers."

Arctic Environmental Impact Assessment (EIA) project

AARHUS UNIVERSITET Fiskaaling 5

General framework of an EIA

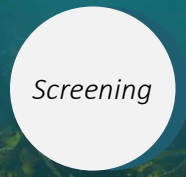
AARHUS UNIVERSITET Fiskaaling 6

General framework of an EIA

AARHUS UNIVERSITET Fiskaaling 7

Screening preceeds the EIA to determine if the project is to undergo an EIA or not

Usually determined through regolatory requirements



AARHUS UNIVERSITET Fiskaaling 8

The content and the extent of the EIA is defined.

Describes the project, and identifies potential impacts and possible alternatives that are to be included in the assessment.

Scoping

AARHUS UNIVERSITET Fiskaaling 9

Baseline data is needed for assessing the impact

Existing data is used in the scoping but baseline data is supplemented during the assessment

Baseline Study

Generally baseline studies are more easily prepared in countries where technical expertise and organised environmental databases are readily available.

AARHUS UNIVERSITET Fiskaaling 10

Involves the prediction and evaluation of impact.

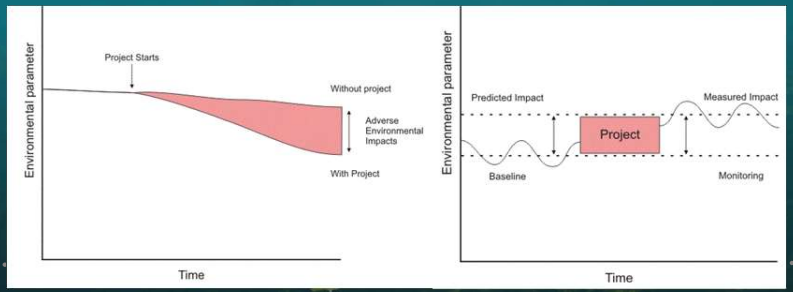
Includeds the prediction of the magnitude, the probability of occurence and the extent of the potenential impact.
→ Eventually defining their significance.

Impact Assessment

Usually the most technical step

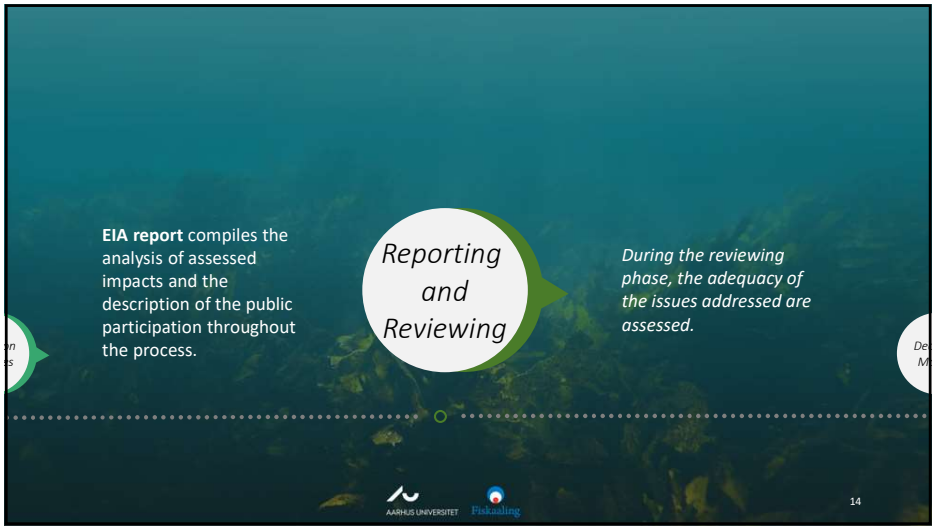
AARHUS UNIVERSITET Fiskaaling 11

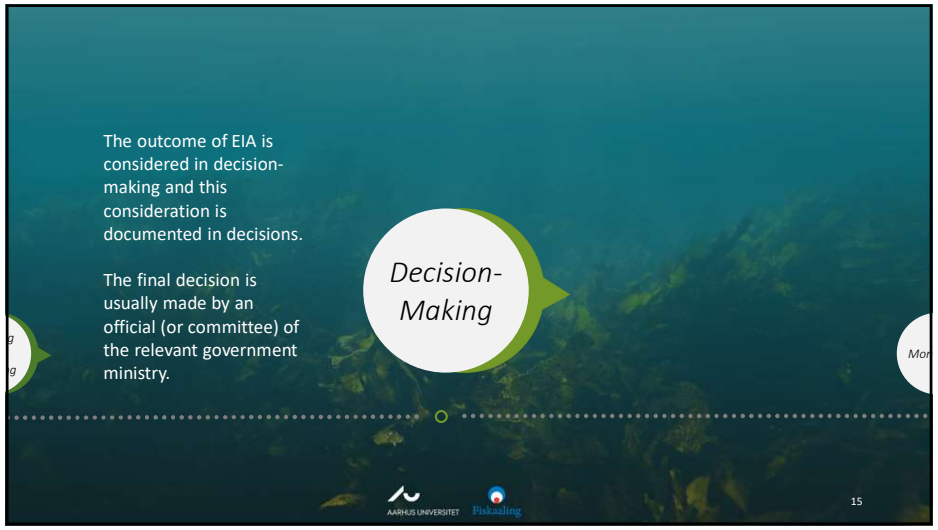
Baseline Study *Impact Assessment*

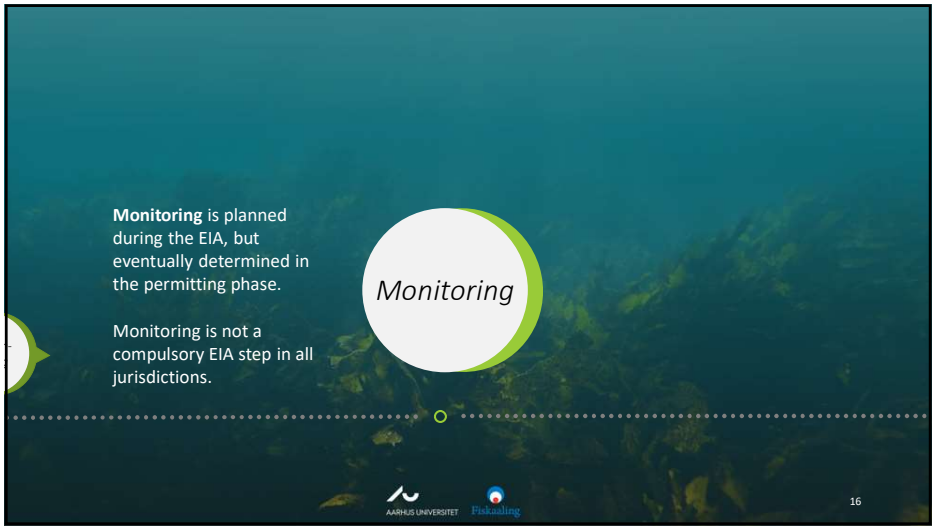


AARHUS UNIVERSITET Fiskaaling 12


Mitigation aims to avoid, minimize, mitigate or, as the last step, compensate for the negative impact of the project.
Potential positive impacts are promoted during this step.
Mitigation Measures
13


EIA report compiles the analysis of assessed impacts and the description of the public participation throughout the process.
Reporting and Reviewing
During the reviewing phase, the adequacy of the issues addressed are assessed.
14


The outcome of EIA is considered in decision-making and this consideration is documented in decisions.
The final decision is usually made by an official (or committee) of the relevant government ministry.
Decision-Making
15


Monitoring is planned during the EIA, but eventually determined in the permitting phase.
Monitoring is not a compulsory EIA step in all jurisdictions.
Monitoring
16

General framework of an EIA

Screening → Scoping → Baseline Study → Impact Assessment → Mitigation Measures → Reporting and Reviewing → Decision-Making → Monitoring

AARHUS UNIVERSITET Fiskaaling 17

ASuReMacro WP2
Baseline Studies Programme Report will include:

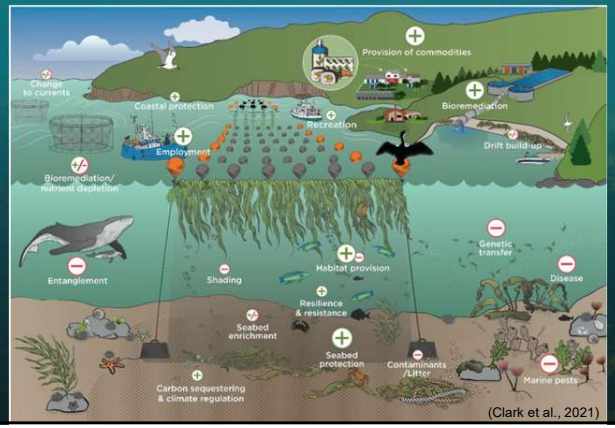
Screening → Scoping → Baseline Study → Impact Assessment → Mitigation Measures → Reporting and Reviewing → Decision-Making → Monitoring

AARHUS UNIVERSITET Fiskaaling 18

Possible environmental effects ?

AARHUS UNIVERSITET Fiskaaling 19

Possible -/+ environmental effects



(Clark et al., 2021)

20

E. How can macroalgal cultivation affect marine ecosystems - Experiences from a Norwegian project

Presenter: **Kasper Hancke**, *Senior Researcher, Norwegian Institute for Water Research (NIVA)*

How do seaweed cultivation affect marine encosystems - experiences from a Norwegian project

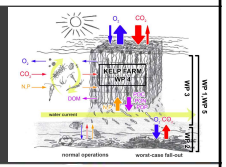
Hvordan kan tangdyrkning påvirke havmiljøet - erfaringer fra et norsk projekt

KELPPRO

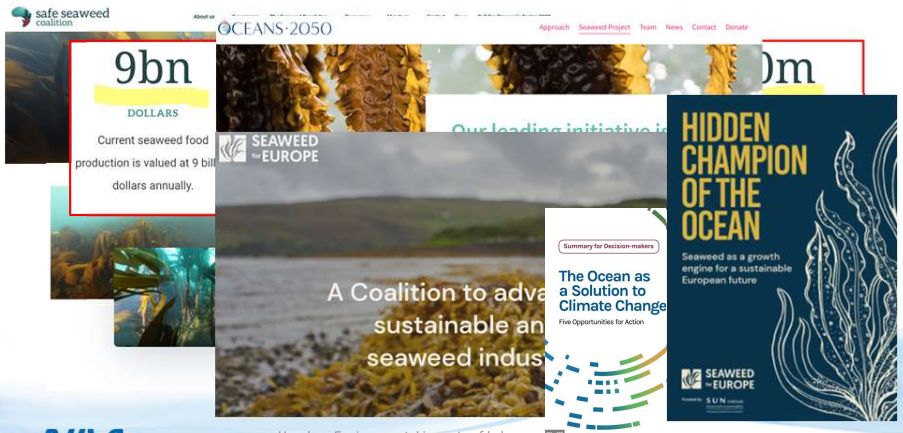
Kelp industrial production: Potential impacts on coastal ecosystems
2017-2020

Kasper Hancke, PhD – Senior Research Scientist at the Norwegian Institute for Water Research (NIVA), Kasper.Hancke@niva.no

ASuReMacro – Seaweed workshop, 15 March 2023, Sudurøy, The Faroes Islands



Seaweed cultivation today, globally & in Europe



Seaweed cultivation today, Norway

Is it possible to create a sustainable seaweed aquaculture?

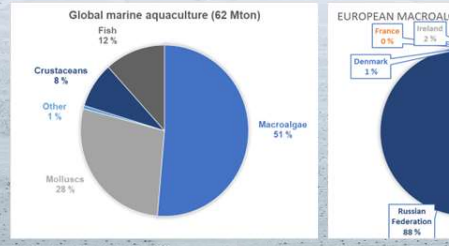
YES!

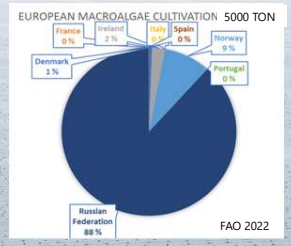
Keywords for success:

1) Play on team with nature!
2) Secure efficient and knowledge-based management, scaled to the growing industry

Why spend time on environmental impacts?

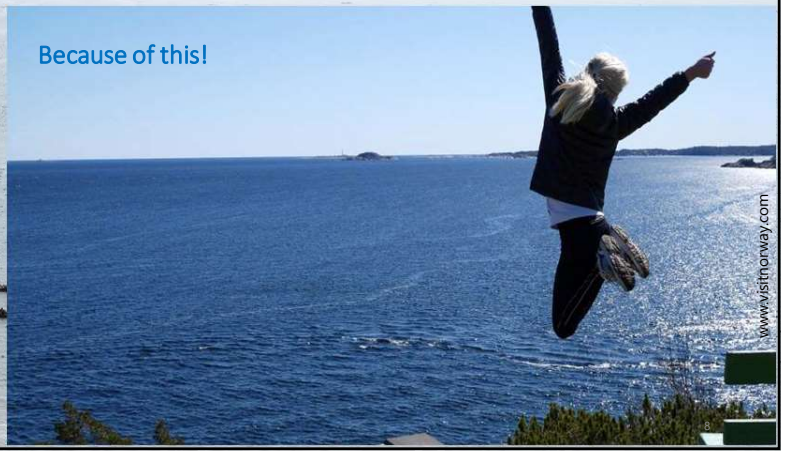
Why spend time on environmental impacts?



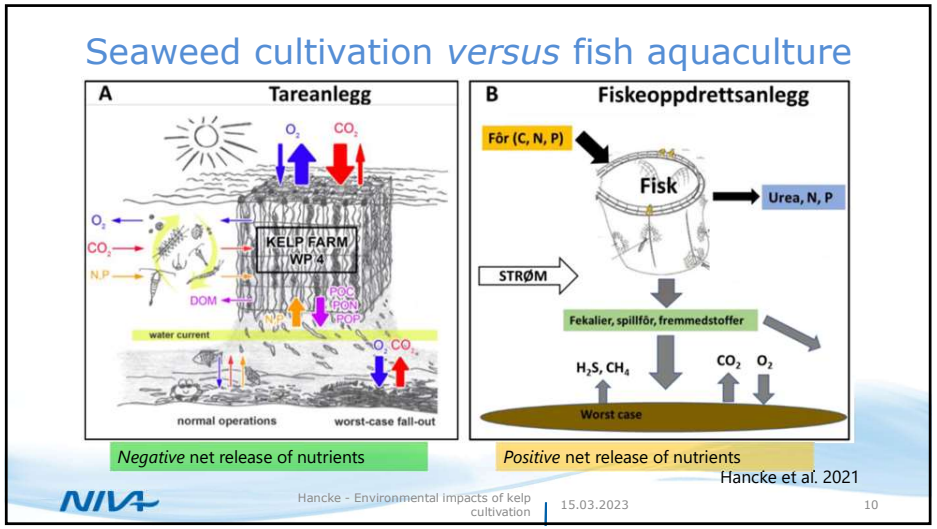


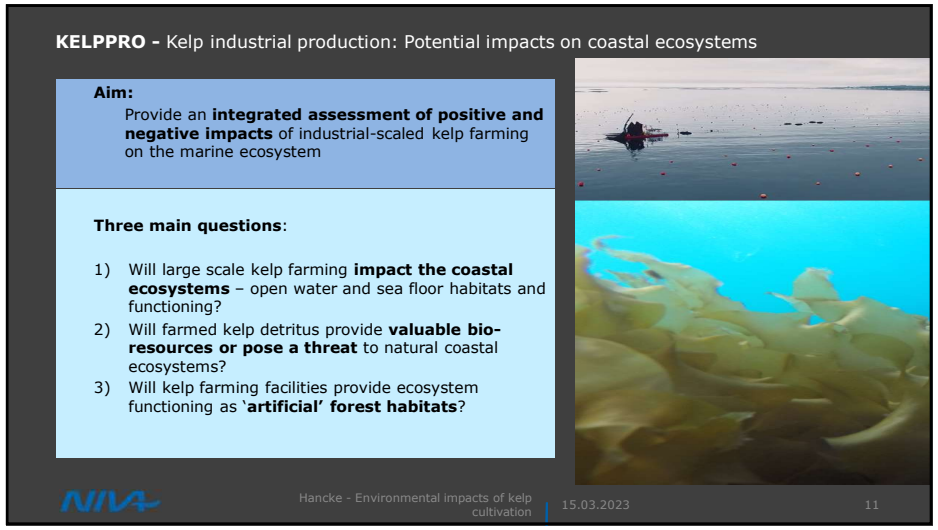
- Global seaweed production **>32 mill. tonnes** (FAO 2022)
- Norway produce ~350 tonnes (2020)
- Faroe Islands 185 tonnes (2021)
- Future prospect in **Norway** is **20 mill. tonnes** by 2050 (Olafsen 2012)
- This requires an area of 2000-3000 km^2, equivalent to an area of ~2 times the area of the Faroe Islands (1396 km^2)

Why spend time on environmental impacts?



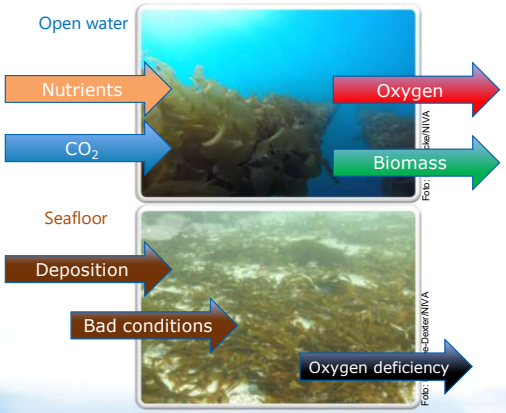

Why spend time on environmental impacts?
.. and because of this ☺
Sangou Bay, Kina
15.03.2023


Seaweed cultivation versus fish aquaculture
A
Tareanlegg
B
Fiskeoppdrettsanlegg
Fôr (C, N, P)
Fisk
Urea, N, P
STRØM
Fekalier, spillfôr, fremmedstoffer
KELP FARM
WP 4
DOM
water current
normal operations
worst-case fall-out
Worst case
Negative net release of nutrients
Positive net release of nutrients
Hancke et al. 2021
Hancke - Environmental impacts of kelp cultivation
15.03.2023
10


KELPPRO - Kelp industrial production: Potential impacts on coastal ecosystems
Aim:
Provide an integrated assessment of positive and negative impacts of industrial-scaled kelp farming on the marine ecosystem
Three main questions:
1) Will large scale kelp farming impact the coastal ecosystems – open water and sea floor habitats and functioning?
2) Will farmed kelp detritus provide valuable bio-resources or pose a threat to natural coastal ecosystems?
3) Will kelp farming facilities provide ecosystem functioning as 'artificial' forest habitats?
Hancke - Environmental impacts of kelp cultivation
15.03.2023
11


a
c
d
Hancke et al. in prep.
Foto av: SES/J. Fundenut

Potential environmental impacts of extensive seaweed cultivation



Positive impacts are

- **Nutrient uptake, reducing eutrophication**
- **CO_2 uptake, reducing ocean acidification and climate mitigation potential**
- **Oxygen** production
- **Increased primary production**
- Stimulate **biodiversity**

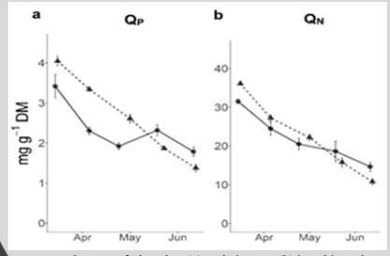
Negative impacts are

- **Reduced light** availability
- **Depletion** of limited nutrients
- **Depositing** of organic matter on the seafloor, leading to
- **poor environmental conditions**,
- **oxygen deficiency**,
- change in natural **biodiversity**
- Spreading of **unwanted species, genetic material and diseases**

Effects on life in the water column

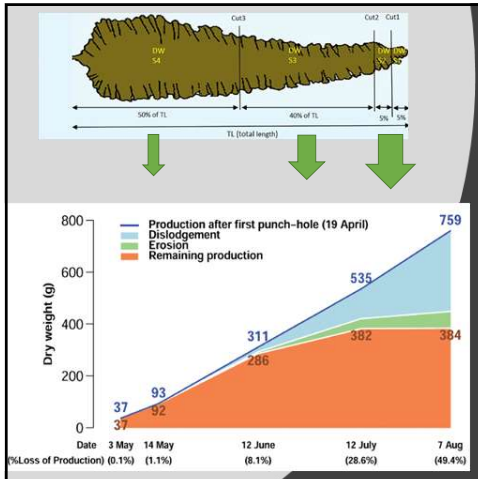
Competition on nutrients between microalgae and kelp?

- Kelp take up nutrients in early spring and growth largely on that throughout the season
- Phytoplankton has a much faster and more efficient nutrient uptake and kelp (>10 times)
- **No significant negative influence found of kelp cultivation on natural phytoplankton and the pelagic foodweb**



Content of phosphor (a) and nitrogen (b) in cultivated kelp (Saccharina latissima), through season 2018.

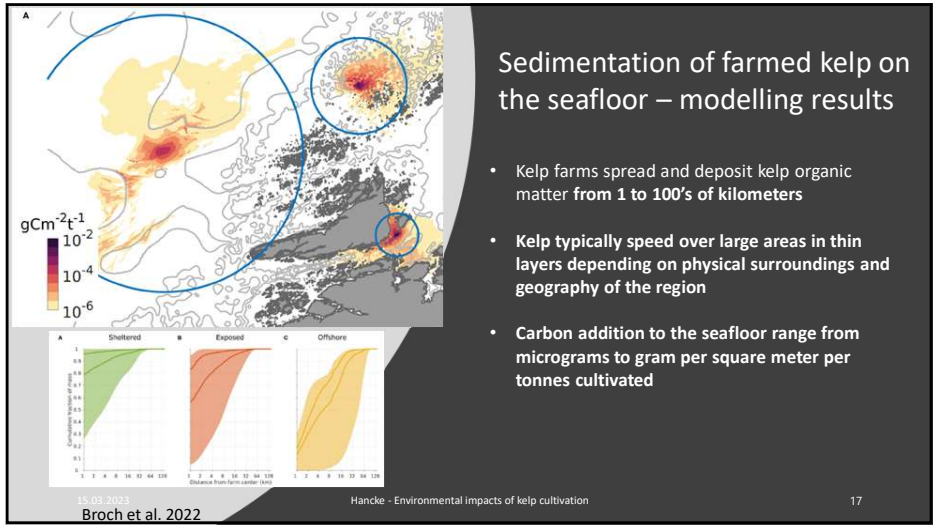
Njåstad, Olsen et al. in prep.



Fieler et al. 2021

Export of organic matter from farmed kelp (Sugar kelp) *Saccharina latissima*

- Kelp farming may export significant of organic matter to the environment
- Farm export 8-15% of harvested biomass under normal production scenarios (Norway)
- >50% after the summer (Fieler et al., 2021)
- In *China*, studies have documented >60% loss of biomass during production (Zhang et al., 2012)



Sedimentation of farmed kelp on the seafloor – modelling results

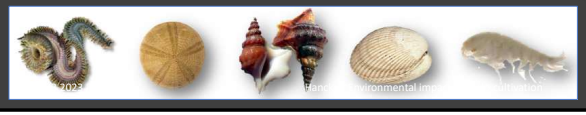
- Kelp farms spread and deposit kelp organic matter **from 1 to 100's of kilometers**
- **Kelp typically speed over large areas in thin layers depending on physical surroundings and geography of the region**
- **Carbon addition to the seafloor range from micrograms to gram per square meter per tonnes cultivated**

Broch et al. 2022

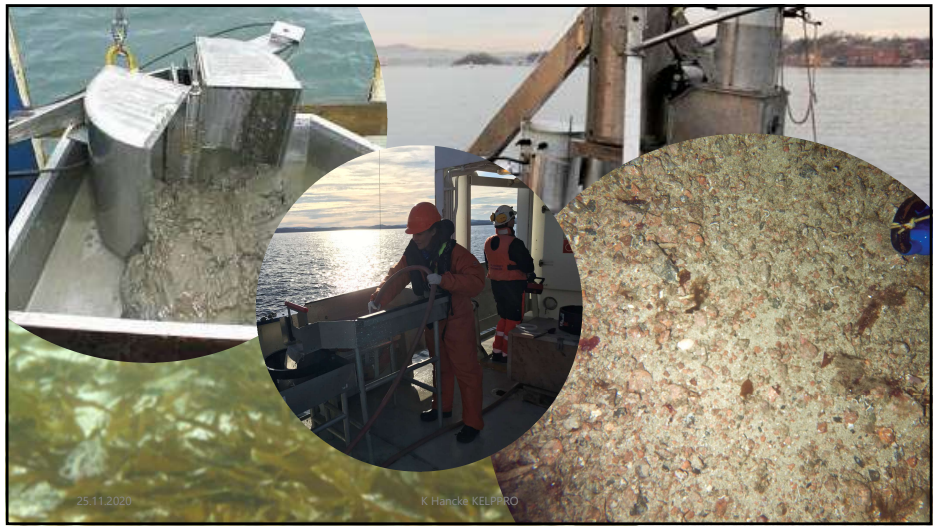
Seafloor biodiversity

Kelp can provide a food source to seafloor fauna or pose a thread to life at the seafloor

- At normal farming conditions effects on seafloor fauna is minimal
- By 'massive' accumulations of kelp on the seafloor (>8 kg m^{-2}) biodiversity decreased and a few species increased in numbers
- **The documented effect was short: >90 % was gone in three months and conditions normalized**



Borgersen et al. in prep.
Hancke et al. in 2022

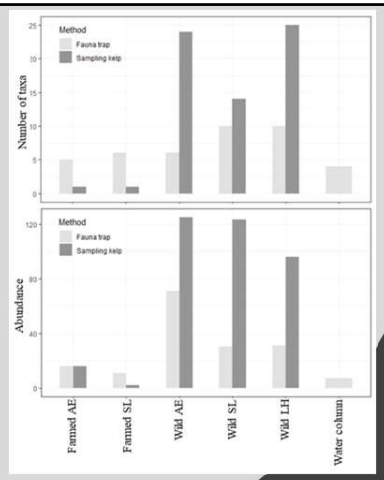


«Large quantities of *Caprella mutica* was found late in the fall

Kelp farms as artificial reef

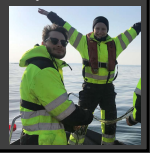
- Kelp farms provide an 'artificial' ecosystem
- Length of the grow season impact the fauna community
- **Kelp farms can be a vector for alien species and spreading of genetic material**

Bekkby et al. 2022

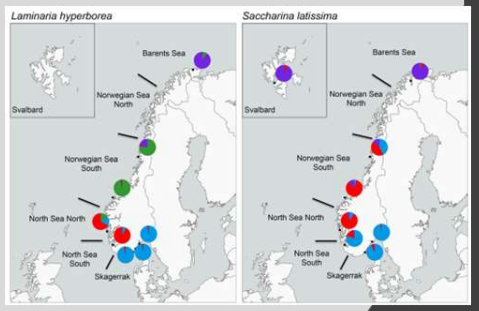


Kelp farms as artificial reef

- Kelp farms had a **lower number of taxa** than wild kelp forests
- Kelp farms had a **lower abundance of fauna** than natural kelp forests
- **SeaBee farms are known to host diseases in Asia**
- Still, scientific documentation **is still sparse on fauna and seaweed diseases**



Bekkby et al. 2022

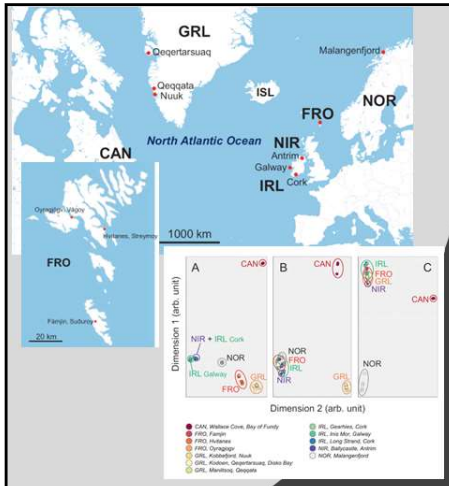


Genetic variability in kelp (wild)

- Genetic variability in wild kelp forests **along the Norwegian coast** (*L. hyperborea and S. latissima*)
- **Little knowledge on the local variability**

Inaba etal 2022

Evenkow et al. 2019



Genetic variability in kelp (wild)

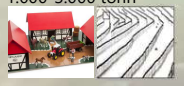
- Genetic variability in wild kelp forests **along the Norwegian coast** (*L. hyperborea and S. latissima*)
- **Little knowledge on the local variability**
- Genetic variability between fjords in the Faroese Islands and across the North Atlantic (*Palmaria & Alaria*)
- **Ask Agnes for details**

Inaba etal 2022

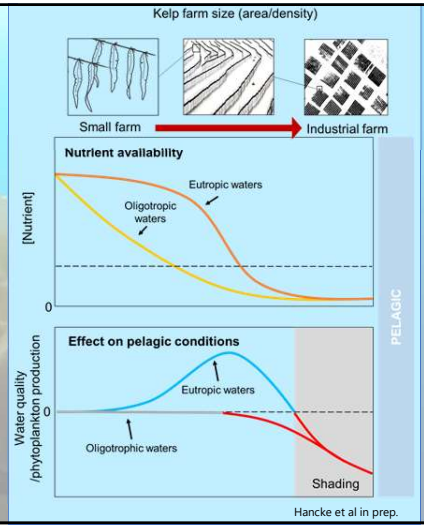
«Size matters», av tareanlegget

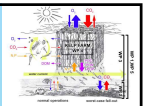
Todays farms: 30-300 tonn

Moderate farms: 1.000-3.000 tonn

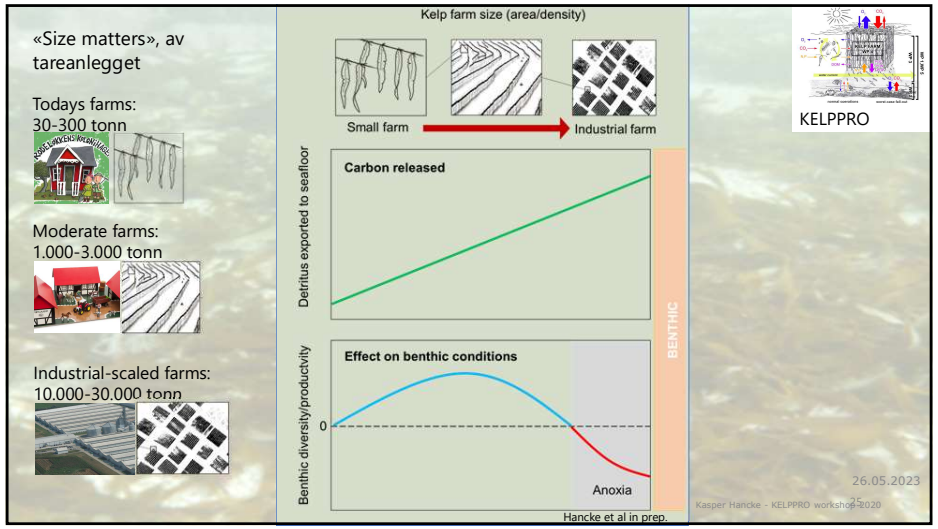


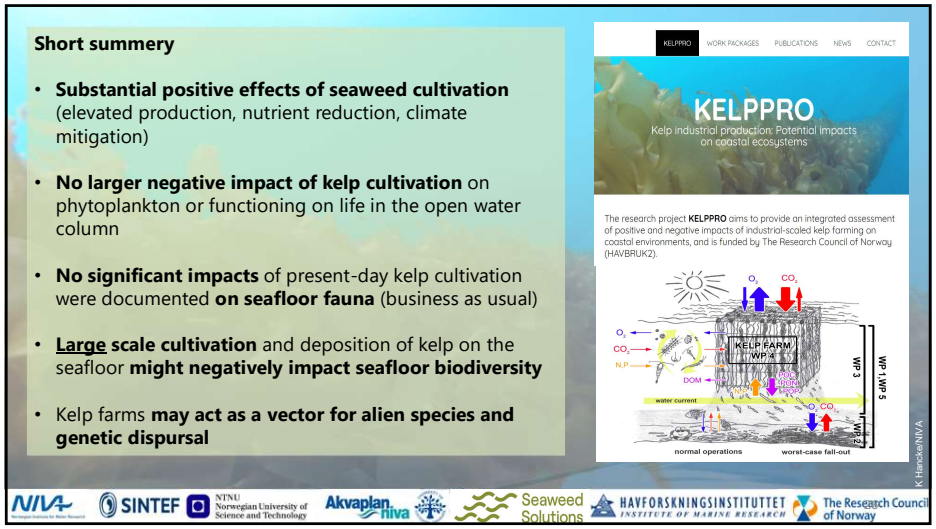
Industrial-scaled farms: 10.000-30.000 tonn

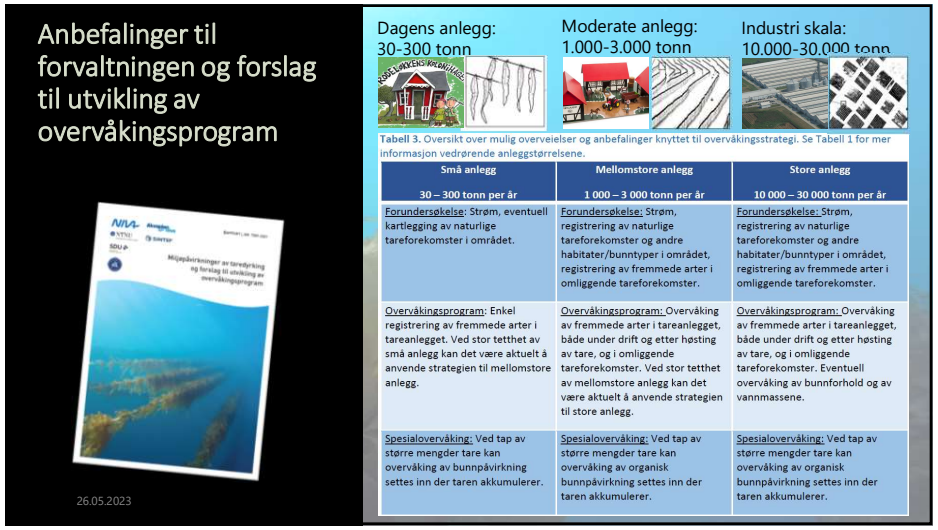




KELPPRO


«Size matters», av tareanlegget
Todays farms:
30-300 tonn
Moderate farms:
1.000-3.000 tonn
Industrial-scaled farms:
10.000-30.000 tonn
Kelp farm size (area/density)
Small farm
Industrial farm
Detritus exported to seafloor
Carbon released
Benthic diversity/productivity
Effect on benthic conditions
0
Anoxia
BENTHIC
KELPPRO
26.05.2023
Hancke et al in prep.
Kasper Hancke - KELPPRO workshop 2020
25

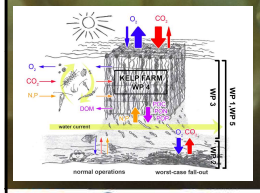

Short summery
Substantial positive effects of seaweed cultivation (elevated production, nutrient reduction, climate mitigation)
No larger negative impact of kelp cultivation on phytoplankton or functioning on life in the open water column
No significant impacts of present-day kelp cultivation were documented on seafloor fauna (business as usual)
Large scale cultivation and deposition of kelp on the seafloor might negatively impact seafloor biodiversity
Kelp farms may act as a vector for alien species and genetic dispursal
KELPPRO
Kelp industrial production: Potential impacts on coastal ecosystems
The research project KELPPRO aims to provide an integrated assessment of positive and negative impacts of industrial-scaled kelp farming on coastal environments, and is funded by The Research Council of Norway (HAVBRUK2).
KELP FARM WP 4
normal operations
worst-case fall-out
K Hancke/NIVA
SINTEF
Norwegian University of Science and Technology
Akvaplan-niva
Seaweed Solutions
HAVFORSKNINGSINSTITUTTET
INSTITUTE OF MARINE RESEARCH
The Research Council of Norway


Anbefalinger til forvaltningen og forslag til utvikling av overvåkingsprogram
Miljøpåvirkninger av taredyrking og forslag til utvikling av overvåkingsprogram
26.05.2023
Dagens anlegg:
30-300 tonn
Moderate anlegg:
1.000-3.000 tonn
Industri skala:
10.000-30.000 tonn
Tabell 3. Oversikt over mulig overveielser og anbefalinger knyttet til overvåkingsstrategi. Se Tabell 1 for mer informasjon vedrørende anleggstørrelsene.
Små anlegg
30 – 300 tonn per år
Mellomstore anlegg
1 000 – 3 000 tonn per år
Store anlegg
10 000 – 30 000 tonn per år
Forundersøkelse: Strøm, eventuell kartlegging av naturlige tareforekomster i området.
Forundersøkelse: Strøm, registrering av naturlige tareforekomster og andre habitater/bunntyper i området, registrering av fremmede arter i omliggende tareforekomster.
Forundersøkelse: Strøm, registrering av naturlige tareforekomster og andre habitater/bunntyper i området, registrering av fremmede arter i omliggende tareforekomster.
Overvåkingsprogram: Enkel registrering av fremmede arter i tareanlegget. Ved stor tetthet av små anlegg kan det være aktuelt å anvende strategien til mellomstore anlegg.
Overvåkingsprogram: Overvåking av fremmede arter i tareanlegget, både under drift og etter høsting av tare, og i omliggende tareforekomster. Ved stor tetthet av mellomstore anlegg kan det være aktuelt å anvende strategien til store anlegg.
Overvåkingsprogram: Overvåking av fremmede arter i tareanlegget, både under drift og etter høsting av tare, og i omliggende tareforekomster. Eventuell overvåking av bunnforhold og av vannmassene.
Spesialovervåking: Ved tap av større mengder tare kan overvåking av bunnpåvirkning settes inn der taren akkumulerer.
Spesialovervåking: Ved tap av større mengder tare kan overvåking av organisk bunnpåvirkning settes inn der taren akkumulerer.
Spesialovervåking: Ved tap av større mengder tare kan overvåking av organisk bunnpåvirkning settes inn der taren akkumulerer.


Publications from KELPPRO – www.kelppro.net
Summarizing report
Website
Scientific and popular publications
Miljøpåvirkninger av taredyrking og forslag til utvikling av overvåkingsprogram
KELPPRO
Kelp industrial production: Potential impacts on coastal ecosystems
Taredyrking er i ferd med å bli stor industri. Er vi forberedt?
Dynamics of erosion from cultivated kelp, Saccharina latissima, and implications for environmental management and carbon sequestration
Hancke - Environmental impacts of kelp cultivation
15.03.2023
28

Thank you for your attention!

Please find more information on **www.kelppro.net**



Acknowledgments to the:

- Researchers
- Technicians
- Students
- Industry members
- Advisory board
- Stakeholders
- The Research Council of Norway for funding!

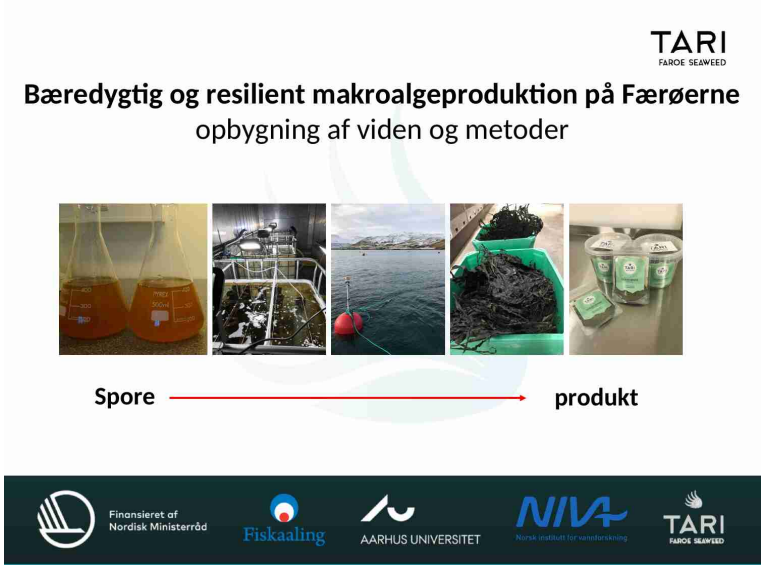
Contact person: Kasper.Hancke@niva.no

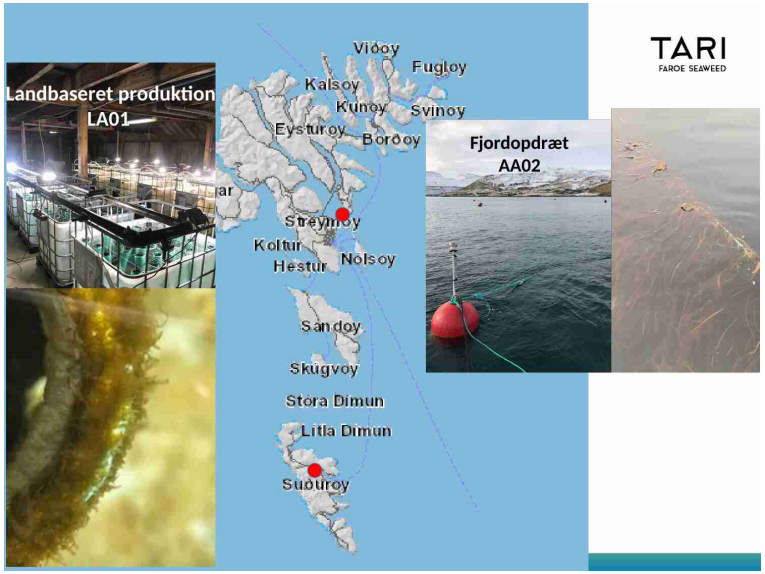
NIVA SINTEF NTNU Norwegian University of Science and Technology Akvaplan-niva Seaweed Solutions HAVFORSKNINGSINSTITUTTET INSTITUTE OF MARINE RESEARCH The Research Council of Norway

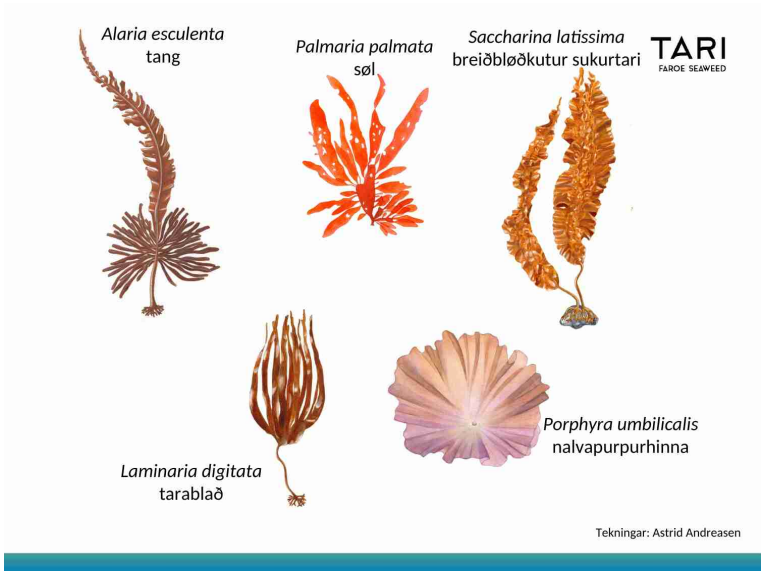
F. Sustainable and resilient macroalgae cultivation on the Faroe Islands - knowledge and method building

Presenter: **Agnes Mols Mortensen**, *CEO, Tari Spf.*


TARI
FAROE SEAWEED
Agnes Mols Mortensen
Taraaling á føroysku firðunum
SALT, 15.03.2023


TARI
FAROE SEAWEED
Bæredygtig og resilient makroalgeproduktion på Færøerne
opbygning af viden og metoder
Spore
produkt
Finansieret af Nordisk Ministerråd
Fiskaaling
AARHUS UNIVERSITET
NIVA
TARI
FAROE SEAWEED


TARI
FAROE SEAWEED
Landbaseret produktion
LA01
Fjordopdræt
AA02
Viðoy
Fugloy
Kalsoy
Kunoy
Svinoy
Eysturoy
Borðoy
Streymoy
Koltur
Hestur
Nolsoy
Sándoy
Skúgvoy
Stóra Dímun
Lítla Dímun
Suðuroy


TARI
FAROE SEAWEED
Alaria esculenta
tang
Palmaria palmata
søl
Saccharina latissima
breiðbløðkutur sukurtari
Laminaria digitata
tarablað
Porphyra umbilicalis
nalvapurpurhinna
Tekningar: Astrid Andreasen

TARI FAROE SEAWEED

Højkvalitets madproduktion

AkvaNest
Patent no. EP3962263A1

TARI FAROE SEAWEED

Hvordan opbygger vi bæredygtige og modstandsdygtige metoder i produktionen?

TARI FAROE SEAWEED

Klækkeri LA-01; Fámjin

- Gammel velegnet bygning
- Velegnet lokalitet
- God adgang til havvand (algeproduktion)
- God adgang til ferskvand (energiproduktion)

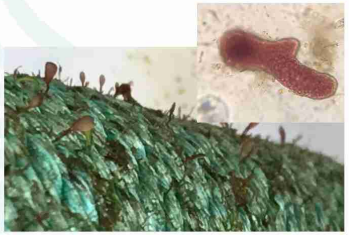
SWGROW

TARI FAROE SEAWEED

Brunalgearterne
Alaria esculenta* & *Saccharina latissima

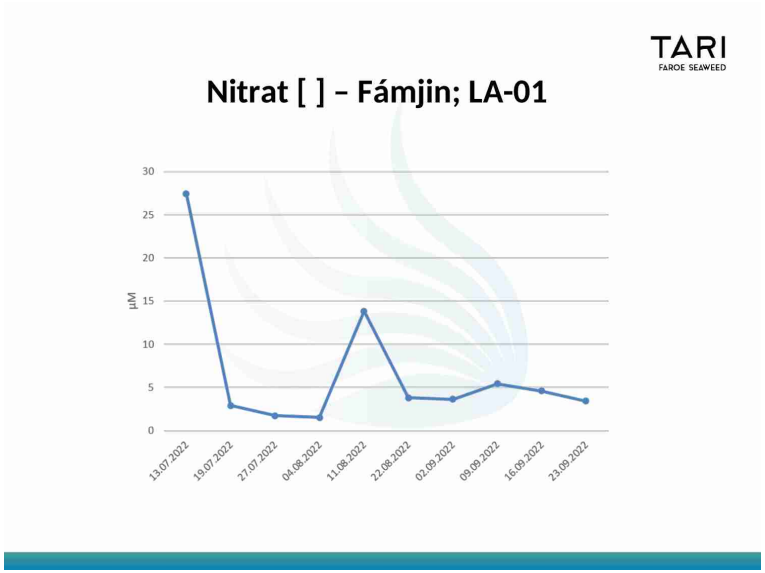
september - februar

Rødalgearten
Palmaria palmata



februar/marts – august/september

- **Bedre udnyttelse af klækkerifaciliteterne**
- **Mulighed for polykultur i stedet for monokultur på fjordanlægget**


TARI
FAROE SEAWEED
Nitrat [ ] – Fámjin; LA-01
µM
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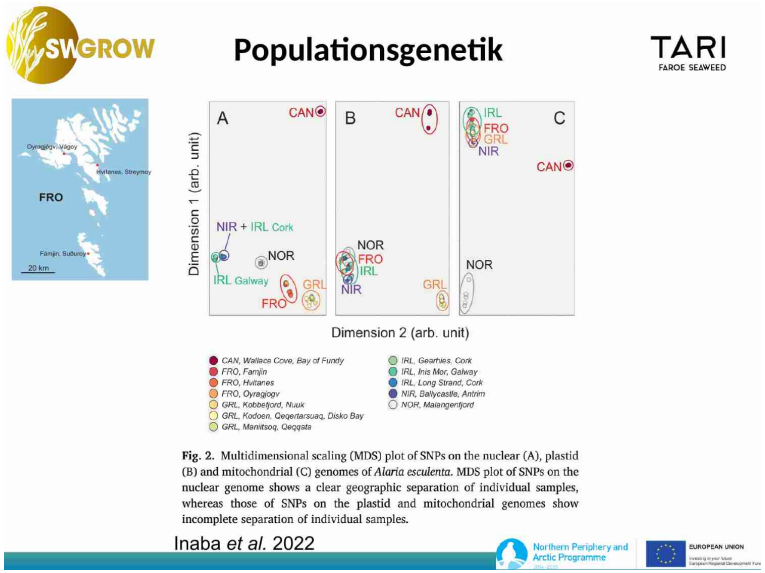
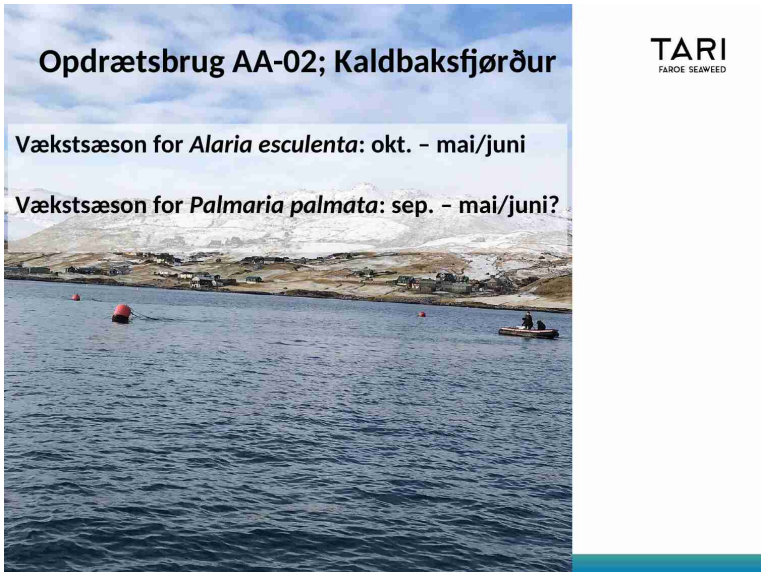
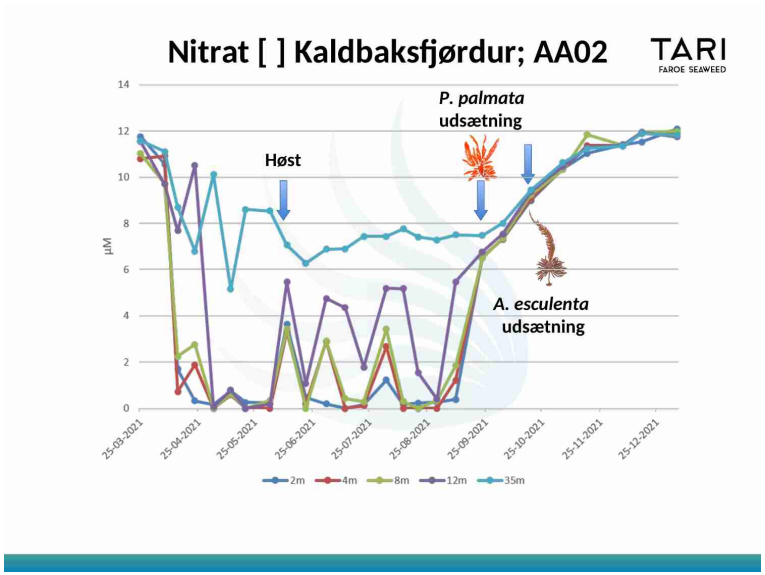
13.07.2022
19.07.2022
27.07.2022
04.08.2022
11.08.2022
22.08.2022
02.09.2022
09.09.2021
16.09.2022
23.09.2022

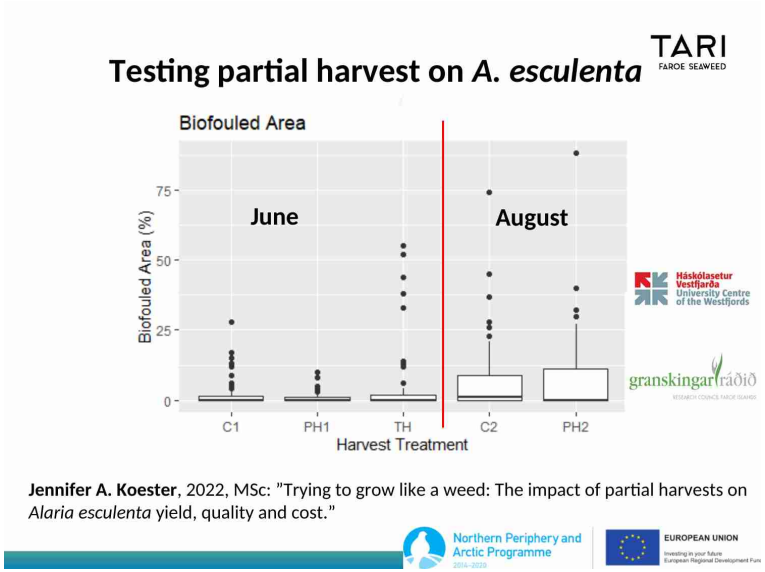

SWGROW
Populationsgenetik
TARI
FAROE SEAWEED
FRO
20 km
A
B
C
CAN
IRL
FRO
GRL
NIR
NIR + IRL Cork
NOR
IRL Galway
Dimension 1 (arb. unit)
Dimension 2 (arb. unit)
CAN, Wallace Cove, Bay of Fundy
FRO, Famjin
FRO, Hvitanes
FRO, Oyragjogv
GRL, Kobbeltjord, Nuuk
GRL, Kodoen, Qeqertarsuaq, Disko Bay
GRL, Manitsoq, Qeqqata
IRL, Gearhies, Cork
IRL, Inis Mor, Galway
IRL, Long Strand, Cork
NIR, Ballycastle, Antrim
NOR, Maiangerfjord
Fig. 2. Multidimensional scaling (MDS) plot of SNPs on the nuclear (A), plastid (B) and mitochondrial (C) genomes of Alaria esculenta. MDS plot of SNPs on the nuclear genome shows a clear geographic separation of individual samples, whereas those of SNPs on the plastid and mitochondrial genomes show incomplete separation of individual samples.
Inaba et al. 2022
Northern Periphery and Arctic Programme
EUROPEAN UNION

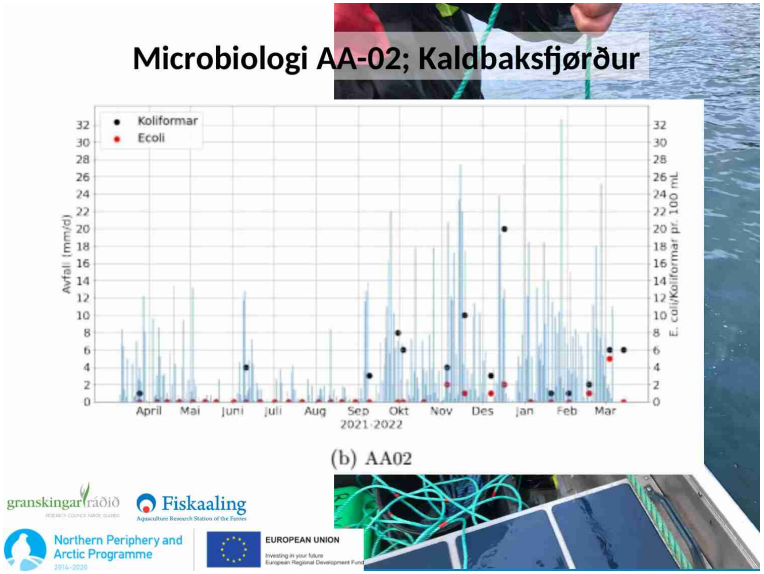

TARI
FAROE SEAWEED
Opdrætsbrug AA-02; Kaldbaksfjørður
Vækstsæson for Alaria esculenta: okt. – mai/juni
Vækstsæson for Palmaria palmata: sep. – mai/juni?


TARI
FAROE SEAWEED
Nitrat [ ] Kaldbaksfjørdur; AA02
P. palmata
udsætning
Høst
A. esculenta
udsætning
µM
14
12
10
8
6
4
2
0
25-03-2021
25-04-2021
25-05-2021
25-06-2021
25-07-2021
25-08-2021
25-09-2021
25-10-2021
25-11-2021
25-12-2021
2m
4m
8m
12m
35m


Høst af højkvalitets *Alaria esculenta* i juni
TARI
FAROE SEAWEED


Juni
August


Testing partial harvest on *A. esculenta*
TARI
FAROE SEAWEED
Biofouled Area
Biofouled Area (%)
June
August
C1
PH1
TH
C2
PH2
Harvest Treatment
Jennifer A. Koester, 2022, MSc: "Trying to grow like a weed: The impact of partial harvests on *Alaria esculenta* yield, quality and cost."
Northern Periphery and Arctic Programme
EUROPEAN UNION


Microbiologi AA-02; Kaldbaksfjørður
Koliformar
Ecoli
Avfall (mm/d)
E. coli/Koliformar pr. 100 mL
April
Mai
juni
juli
Aug
Sep
Okt
Nov
Des
jan
Feb
Mar
2021-2022
(b) AA02
Fiskaaling
Northern Periphery and Arctic Programme
EUROPEAN UNION


TARI
FAROE SEAWEED
Færøske tangskove som opvækststed for torsk og sej
forsøg på at undersøge sammenhæng mellem tangskoven og disse fiskearter
Arbejdspakker
1. Undersøgelse af torsk og sej
HAVSTOVAN
2. Undersøgelse af tangskoven
TARI
FAROE SEAWEED
3. eDNA undersøgelse
Fiskaaling
FISKIVINNU
GRANSKING


TARI
FAROE SEAWEED

G. Lessons learned and future approaches on measuring impact on the marine ecosystem related to macroalgae cultivation

Presenter: **Ólavur Gregersen**, *CEO, Ocean Rainforest*

OCEAN RAINFOREST
SUSTAINABLE NORDIC SEAWEED

Lessons learnt and future approaches on measuring impact on the marine ecosystem related to marco algae cultivation

Olavur Gregersen
CEO, Ocean Rainforest

March 15, 2023

The pain – and the gain!

PROBLEMS TO SOLVE:

Global shortages of sustainable and healthy feed and food.

To mitigate climate change.

OUR SOLUTION:

Cultivate seaweed as they are among the fastest growing crops on the planet. To grow, they only need sunlight, CO_2 and natural nutrients.

THE MARKET

Increasing demand in Europe and North America to use seaweed in human food, animal feed, as bio stimulants for agriculture, and replacing fossil-based packaging material (bio-plastic).

The potential of seaweed

Sustainably cultivated seaweed

"The potential for providing large quantities of food and biomass from seaweed mariculture is much larger than for any other group of marine organisms."

Ref. SAPEA 2017 Evidence Review Report, more than 100 European scie nce academies.

3

Win-win solutions proving environmental benefits

OCEAN RAINFOREST

13 CLIMATE ACTION

14 LIFE BELOW WATER

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

CO_2 uptake

Creates ecosystems

Uptake of nutrients (bioremediation)

Reduces global heating and acidification of the oceans

Provides shelter, nursery habitat and feeding chamber for fish and other marine animals

No use of land, fertilizer or freshwater

4

Establishment of a cultivation site

OCEAN RAINFOREST

Feasibility Study	Finite Element Analysis	Front End Engineering Design	Permit processing
Final Rig Configuration	Deployment	Operation (seeding and harvesting)	Monitoring & maintenance

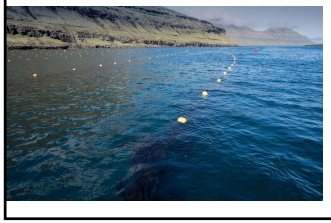
Feasibility Study

Primary parameters

- Current (speed and direction)
- Wave (significant wave heights and length)
- Temperature (mean over year)
- Bathymetry (depth of seawater)
- Benthic environment (sand, mud, rocks, etc.)
- Wind rose and speed (average over year)
- Natural populations (macro algae species)
- Nutrient profiles

Secondary parameters

- Main sailing/shipping routes
- Sanctuary constraints due to habitat/environment
- Marine mammals' behavior in the area



Optimal cultivation conditions for *S. latissima* and *A. esculenta*

Based on the experience of Ocean Rainforest optimal seaweed cultivation requires:

- Water depth between 30-150m (100-500ft)
- A maximum sea temperature of 15 C (59F)
- Exposed with respect to wave (Max 10m significant) and current (max 1.5m/sec)
- At minimum 3 µM for nutrient availability

7

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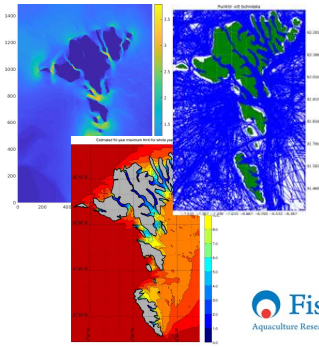
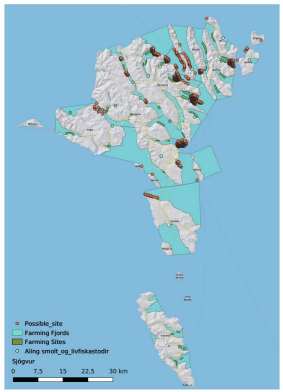
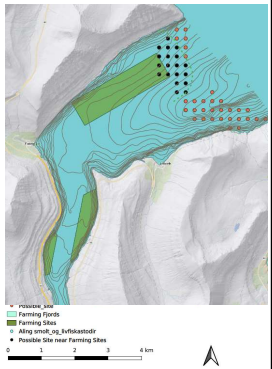
Site selection in the Faroe Islands

- Model for suitable sites based on current, depth and waves.







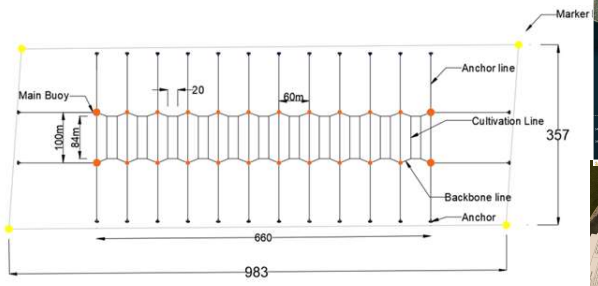
Fiskaaling
Aquaculture Research Station of the Faroes

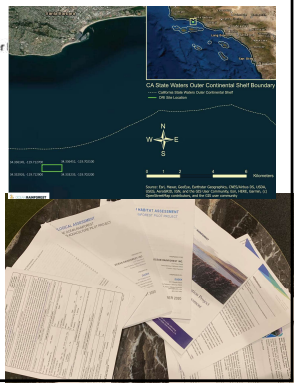
AquaVitae

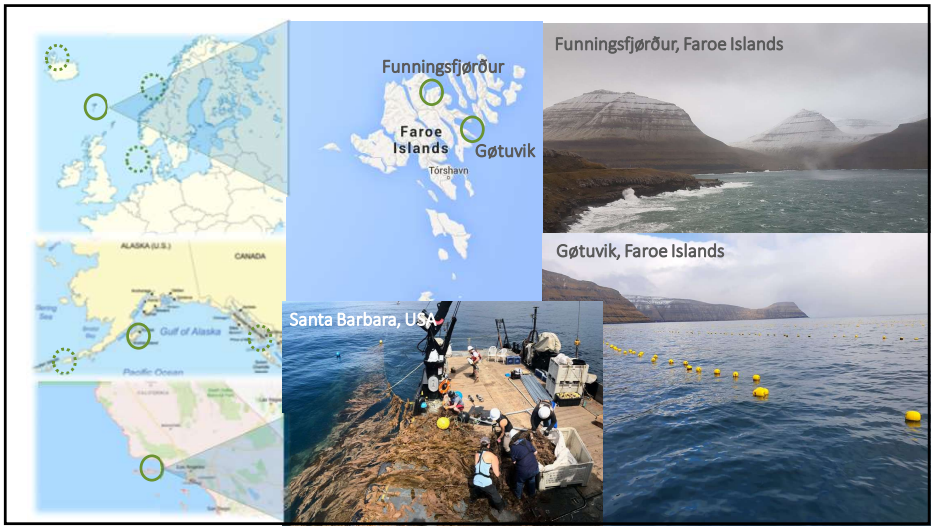
OCEAN RAINFOREST
SUSTAINABLE NORDIC SEAWEED

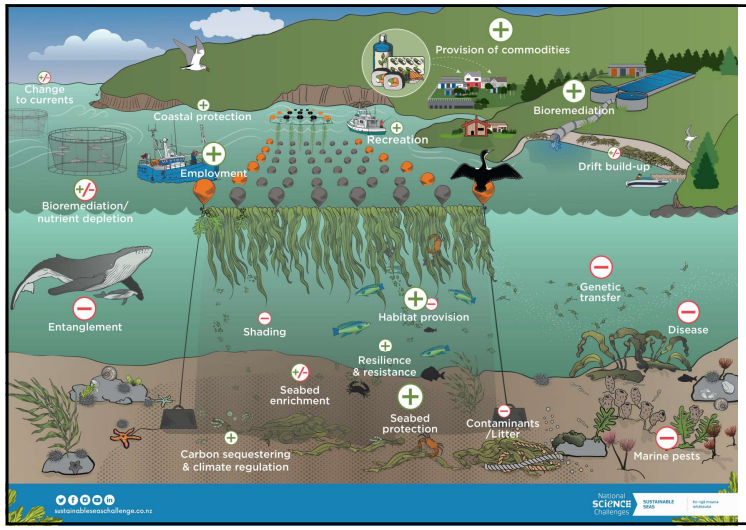
Front End Engineering Design and permit processing

OCEAN RAINFOREST









Possible ecosystem services and negative environmental effects associated with seaweed aquaculture in coastal environments

Source: Stocktake and characterisation of New Zealand's seaweed sector: Environmental effects of seaweed wild-harvest and aquaculture, Graphic by Revell Design

SEAMARK
Seaweed-based Market Applications

WP9: Ecosystem services and LCA

WP LEADER: WUR
TASK LEADER: SJOKOVIN – BLUE RESOURCE, OCEAN RAINFOREST
OTHER CONTRIBUTORS: SUBMARINER, ALGOLESKO, ALGAIA, NOFIMA, ALGAPLUS, FERMENTATION EXPERTS,
9TH OF JANUARY 2023, WP LEADER MEETING, ROSCOFF

Co-funded by the European Union

HORIZON PROJECT: 101060379 — SEAMARK

12

Methodology for data collection for Ecosystem Services (framework)

For ecosystem services (ES):

- An overview of categorized ecosystem services, comparing various categorisations
- An overview of methodologies used to quantify and valuate ES in literature
- Decision process for specific partners to decide and plan the final data collection

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement No 101060379

Specific protocol 2: ROV monitoring

Related hazards:

- Inorganic waste as result of seaweed farming practices
- Accumulated algae on the seafloor after harvest

Method

- BACI experiment
- ROV survey before installation and 2 weeks after harvest

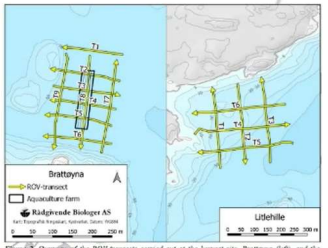


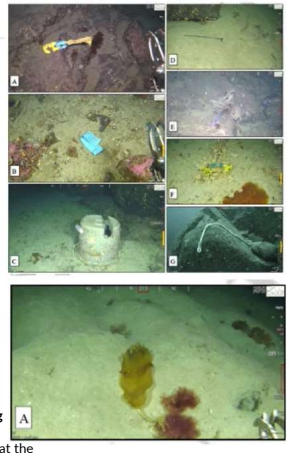
Figure 2. Overview of the ROV-transects carried out at the harvest site, Brattøyna (left), and the reference site, Litlehille (right).

Presented by **Sander Van Den Burg**
Senior Researcher
Wageningen Economic Research, at the International Seaweed Symposium, 2023

22

Results

- Debris is present, some can be related to seaweed farming but not all
- Post-harvest winged kelp made up roughly 1/3 of all macroalgae debris on the sea floor,
- Debris registered in the pre-harvest survey were mainly other species of macroalgae.
- Sea bottom underneath the farm did not appear impacted in a negative manner by macroalgae debris.



Presented by **Sander Van Den Burg**
Senior Researcher
Wageningen Economic Research, at the International Seaweed Symposium, 2023

Recommendations for this method

Value of the method:

- Established methodology for salmon farming
- Direct insight into inorganic waste

But also:

- Expensive method
- Difficult to find good reference site

Suggested when installing a seaweed farm or adapting design, not regularly

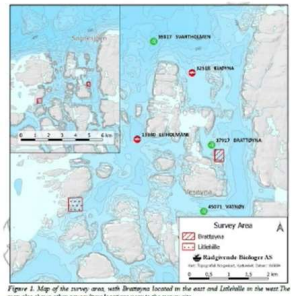


Figure 1. Map of the survey area, with Brattøyna located in the east and Litlehille in the west. The map also shows other aquaculture locations near to the survey site.

Presented by **Sander Van Den Burg**
Senior Researcher
Wageningen Economic Research, at the International Seaweed Symposium, 2023

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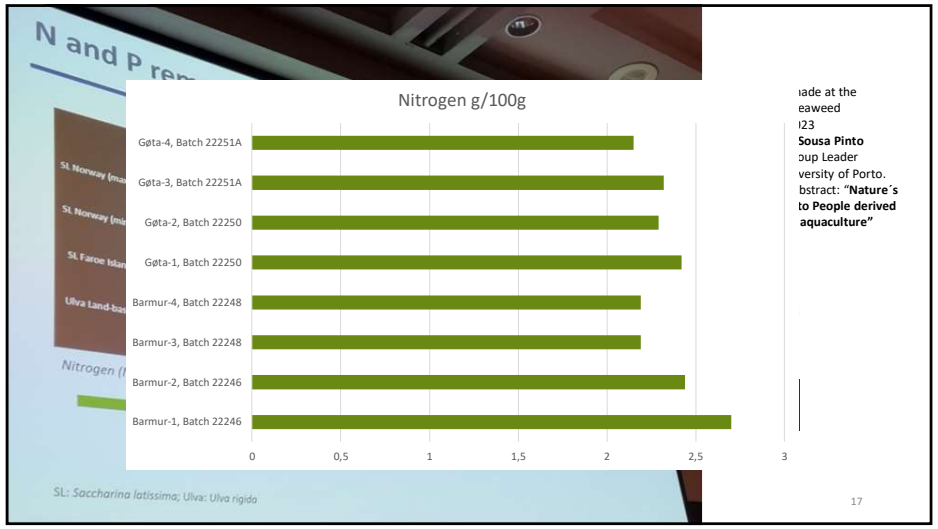
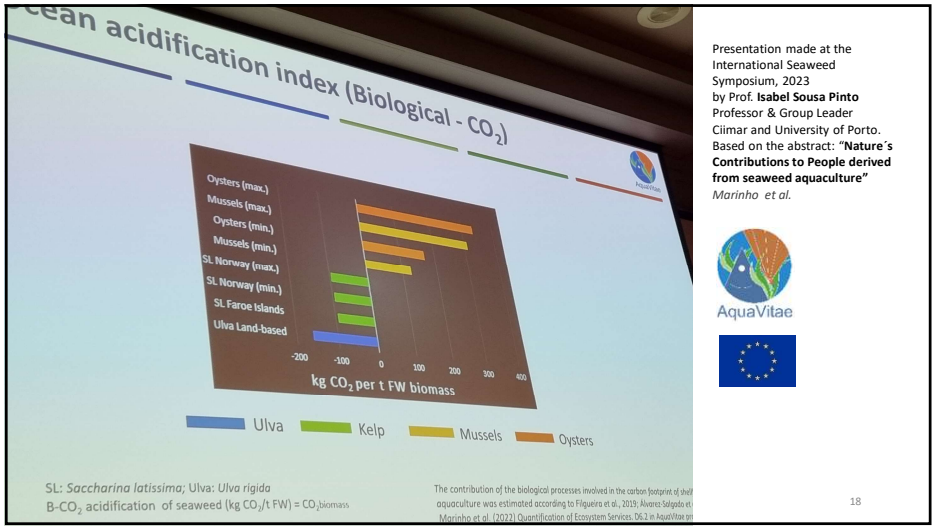




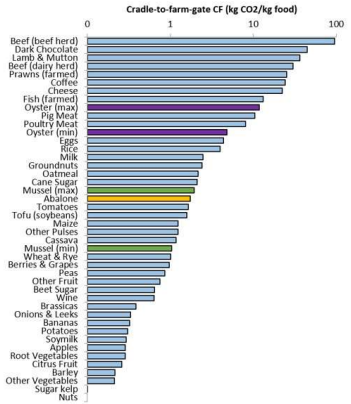
Presentation made at the International Seaweed Symposium, 2023
by Prof. **Isabel Sousa Pinto**
Professor & Group Leader
Ciimar and University of Porto.
Based on the abstract: **"Nature´s Contributions to People derived from seaweed aquaculture"**
Marinho et al.

AquaVitae

Solution – Seaweed

Carbon dioxide footprint of seaweed

Compared to other food production systems, sugar kelp/seaweed (16 gCO_2 per kg of food) reported the lowest carbon footprint, just higher than the CF of nuts and smaller than any other primary production system.



Source: Deliverable 6.2: New species, processes and products contributing to increased production and improved sustainability in emerging low trophic, and existing low and high trophic aquaculture value chains; The Horizon 2020 project Aavitae, 2022.

19

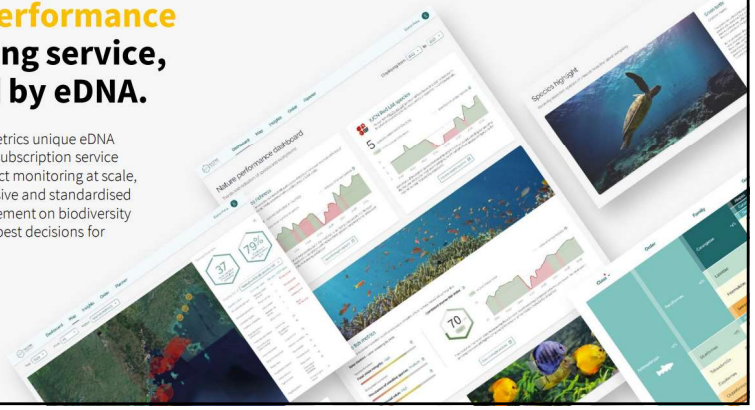
AquaVitae

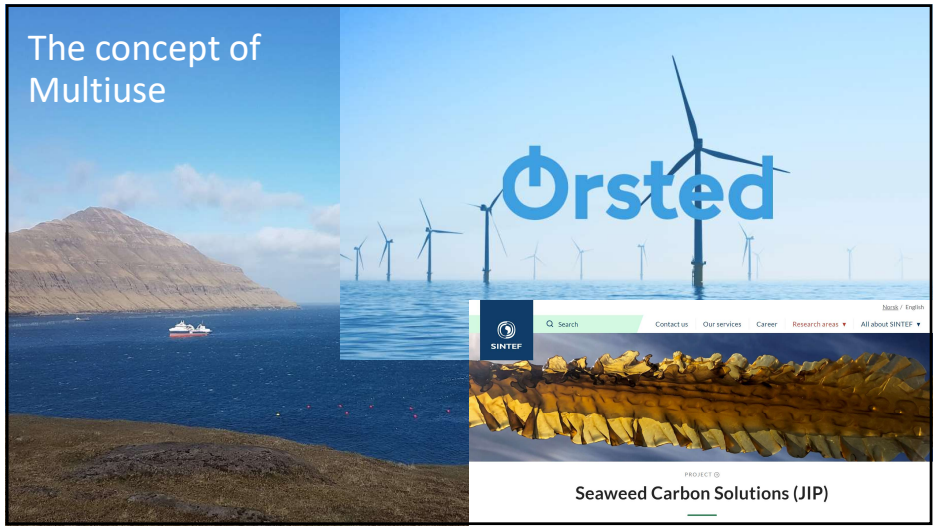
OCEAN RAINFOREST

NATURE METRICS

The world's first nature performance monitoring service, powered by eDNA.

Powered by NatureMetrics unique eDNA technology, the new subscription service provides nature impact monitoring at scale, enabling comprehensive and standardised performance measurement on biodiversity health, to inform the best decisions for business and nature.





Conclusion

- In general, no negative impact on the marine ecosystem
- Potential positive impact on the marine biodiversity and biostimulants
- Development of measurement procedures in process
- Need of cost effective monitoring and dissemination tools on quantification and valorization of ecosystem services related to seaweed cultivation

Thank you!

Contact

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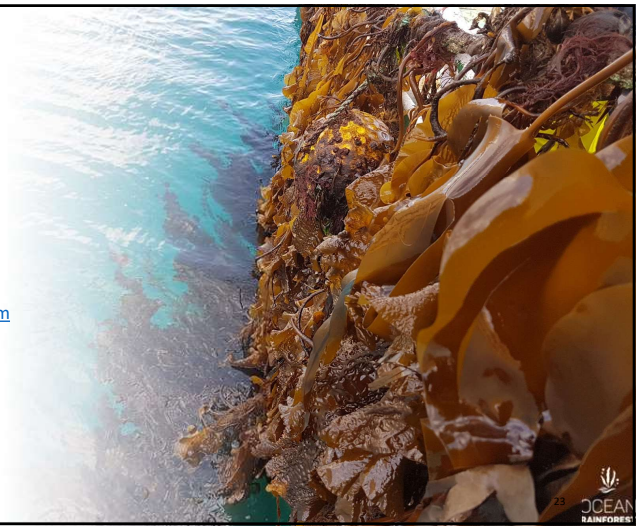
Olavur@oceanrainforest.com
O: +298 310700
M: +298 233080



H. Macroalgae cultivation in Norway. Today's status and future plans

Presenter: **Gunhild Borgersen**, *Researcher, Norwegian Institute for Water Research (NIVA)*


Tare/tang dyrking i Norge: status og planer fremover
ASuReMacro verkstova15. mars 2023
Øravik, Færøyene
Gunhild Borgersen, NIVA
Foto: Kasper Hancke (NIVA)


Tare/tang dyrking i Norge: status og planer fremover
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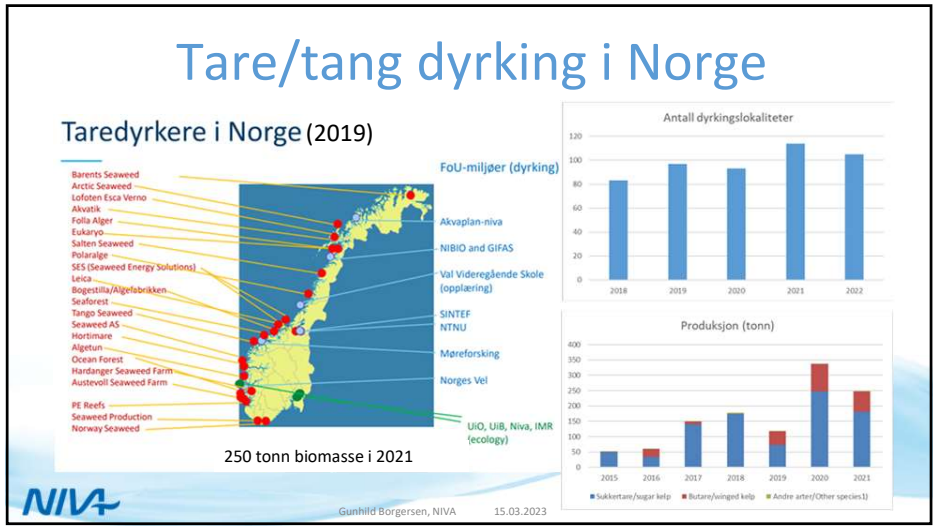
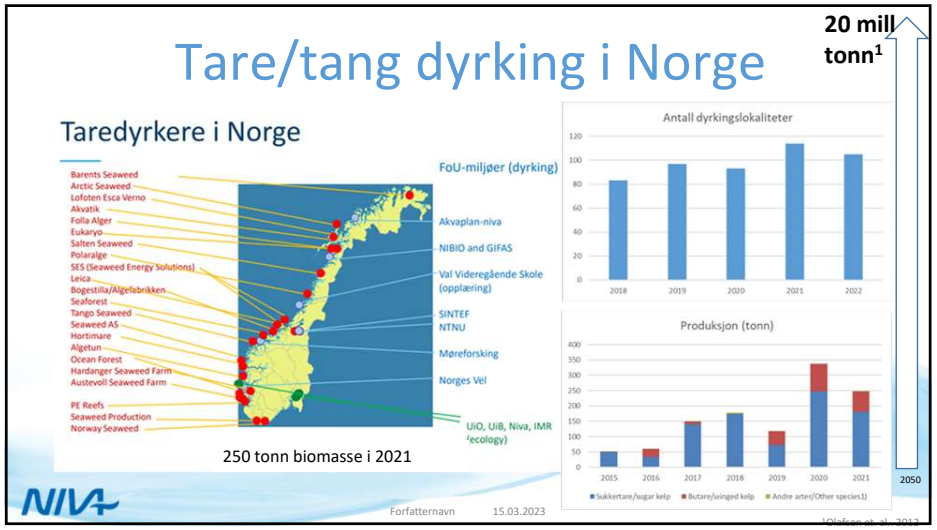
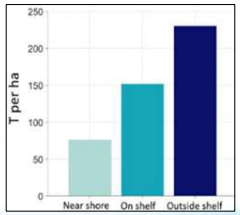
Foto: Kasper Hancke (NIVA)

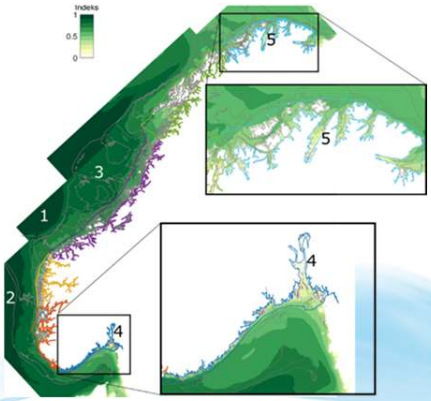

Tare/tang dyrking i Norge
Taredyrkere i Norge (2019)
FoU-miljøer (dyrking)
Akvaplan-niva
NIBIO and GIFAS
Val Videregående Skole (opplæring)
SINTEF NTNU
Møreforsking
Norges Vel
UiO, UiB, Niva, IMR (ecology)
Antall dyrkingslokaliteter
Produksjon (tonn)
250 tonn biomasse i 2021
Gunhild Borgersen, NIVA 15.03.2023


Tare/tang dyrking i Norge
20 mill tonn[1]
Taredyrkere i Norge
FoU-miljøer (dyrking)
Akvaplan-niva
NIBIO and GIFAS
Val Videregående Skole (opplæring)
SINTEF NTNU
Møreforsking
Norges Vel
UiO, UiB, Niva, IMR (ecology)
Antall dyrkingslokaliteter
Produksjon (tonn)
250 tonn biomasse i 2021
2050
Forfatternavn 15.03.2023

Dyrkingspotensial i Norge

- Høyest potensiale for tangdyrking offshore

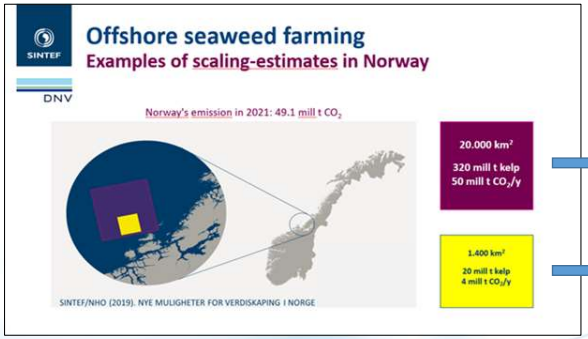




NIVA

Broch et al., 2019 (https://doi.org/10.3389/fmars.2018.00529)
Forbord et al., 2020 (https://doi.org/10.1007/s10811-020-02038-y)

Dyrkingspotensial i Norge



~ Norges utslipp av CO^2 i 2021

Forventet norsk tareproduksjon i 2050

NIVA

Dyrking av sukkertare, en naturbasert metode for aktiv karbonfangst

SINTEF
DNV
equinor
AkerBP

Seaweed Carbon Solutions – a joint industry project

Teknologi for et bedre samfunn

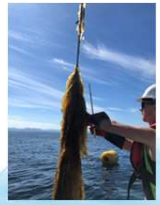
Seaweed Carbon Solutions

Joint Industry Project

SINTEF
DNV
AkerBP
equinor
United Nations Global Compact
REV Ocean
NIVA
south pole
Seaweed Solutions

GOAL: Develop **scalable** technology for open ocean **seaweed-CDR** (carbon dioxide removal) with a potential for removal of **1 mill ton CO_2 in 2030** by climate positive products or solutions.

- Test **sea farm modules** under offshore conditions
- Test **sinking at sea and biochar on land** as carbon storage
- Assess positive and negative **environmental impacts**
- Quantify actual and potential **net CO_2-removal**
- Outline seaweed **CO_2-offset** mechanism and business cases



PILOT 2022-2024
5 M€ budget
Option for DEMO 2025-2027
Open for more partners

NIVA

Possible CDR solution

Biochar made from seaweed for different carbon storing applications

Seaweed Carbon Solutions
Joint Industry Project

Production potential kelp biochar:

- 600-800 tons per km² sea surface

CDR = Carbon dioxide removal

Possible CDR solution

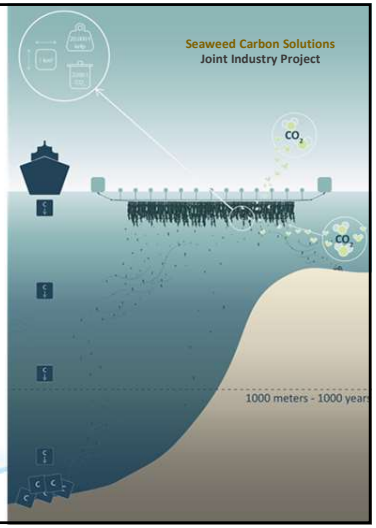
Sinking of kelp biomass for long term storage in sediments

Seaweed Carbon Solutions
Joint Industry Project

Deponering av (store) mengder tarebiomasse på havbunnen kan gi

- dårlig økologisk tilstand
- oksygenmangel
- endring i naturlig biologisk mangfold
- spredning av uønskede arter og gener

Må overvåke miljøeffekter

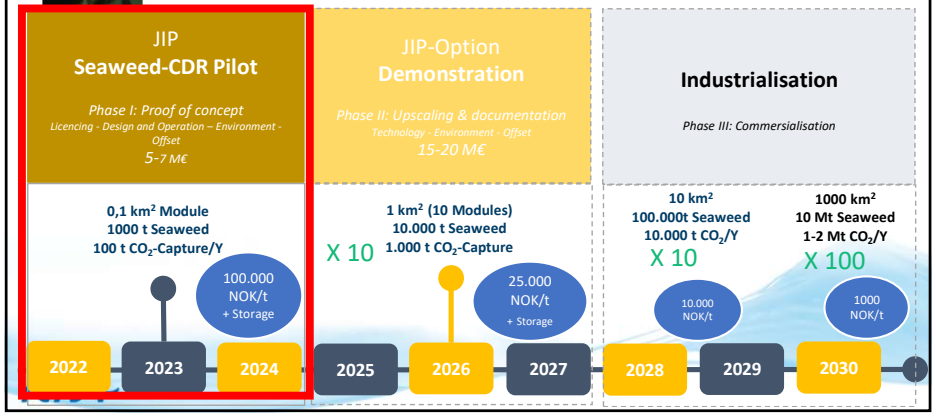


CDR = Carbon dioxide removal

Seaweed Carbon Solutions

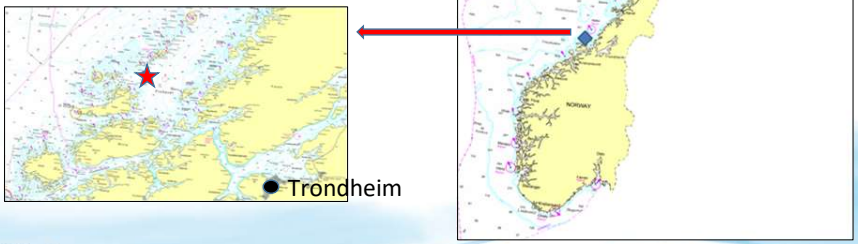
Joint Industry Project

Timeline – JIP & Industrial development



Offshore pilotanlegg

Det søkes om etablering av sjøanlegg på **650 da** for inntil **800 tonn** biomasseproduksjon. Totalt areal inkludert fortøyningsareal er **800 da**



Environmental impact

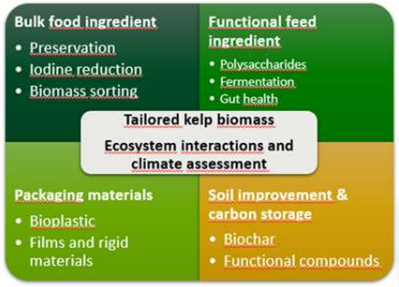
- Monitoring of the effects of dissolved nutrients removal by the large scaled biomass production.
- Monitoring of the seaweed farm as a temporary habitat.
- Evaluation of effects on the benthic ecosystem under the farm.
- Quantify particulate organic carbon (POC) released from farms
- **Base-line surveys prior to production**

GP Seaweed

Innovasjon Norge

The Research Council of Norway

New products from cultivated seaweed for blue-green value-chains



SINTEF NTNU NIVA

Seaweed Solutions LERØY

ALGEA B'ZEOS MIKO

Felleskjøpet CircleGreen

Ecosystem interactions and climate assessment

- Assessment of biodiversity, alien and threatened species associated with kelp farms
- Disease in seaweeds – effects on production and potential environmental stressor
- Reduced GHG emissions – quantify carbon removal
- CO_2-emissions related to the processing and production processes
- Mathematical modelling


Oppsummering
• Taredyrking i Norge: oppskaleres og flyttes offshore?
• Økt produksjon krever store arealer, og risiko for negative miljøkonsekvenser øker
• Taredyrking kan være et positivt klimatiltak
• Takk for meg!
Foto: Kasper Hancke (NIVA)
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