Aksel Andrè Wiik Martinsen
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Mathias Bueng Gjone

Bachelor's thesis

Efficient Production and Deployment of Kelp Line

Effektiv produksjon og utsetting av tareline

May 2021

NTNU
Norwegian University of Science and Technology
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REPORT BACHELOR THESIS

Title (Both in Norwegian and English)
Efficient production and deployment of kelp line **Effektiv produksjon og utsetting av tareline**
Project number **MTP-K-2021-08**
Author(s) Aksel Andrè Wiik Martinsen Hermann Peter Schips Mathias Bueng Gjone
Company (external) Seaweed Solutions AS
Supervisor NTNU Detlef Blankenburg
Report is OPEN/CLOSED OPEN
Date 20.05.2021

Short abstract (Both in Norwegian and English)

This thesis deals with concept development of a new process for efficient production and deployment of kelp line. The aim of the thesis is to develop a method that will be more efficient than the current method for deployment. This will facilitate further industrialization of kelp farming.

Denne oppgaven omhandler konseptutvikling av en ny prosess for effektiv produksjon og utsetting av tareline. Målet med oppgaven er å utvikle en metode som skal være mer effektivt enn dagens metode for utsett. Dette skal tilrettelegge for videre industrialisering av tareoppdrett.

Stikkord:	Keywords:
Tareoppdrett, konseptutvikling, effektivisering	Kelp farming, concept development, streamlining

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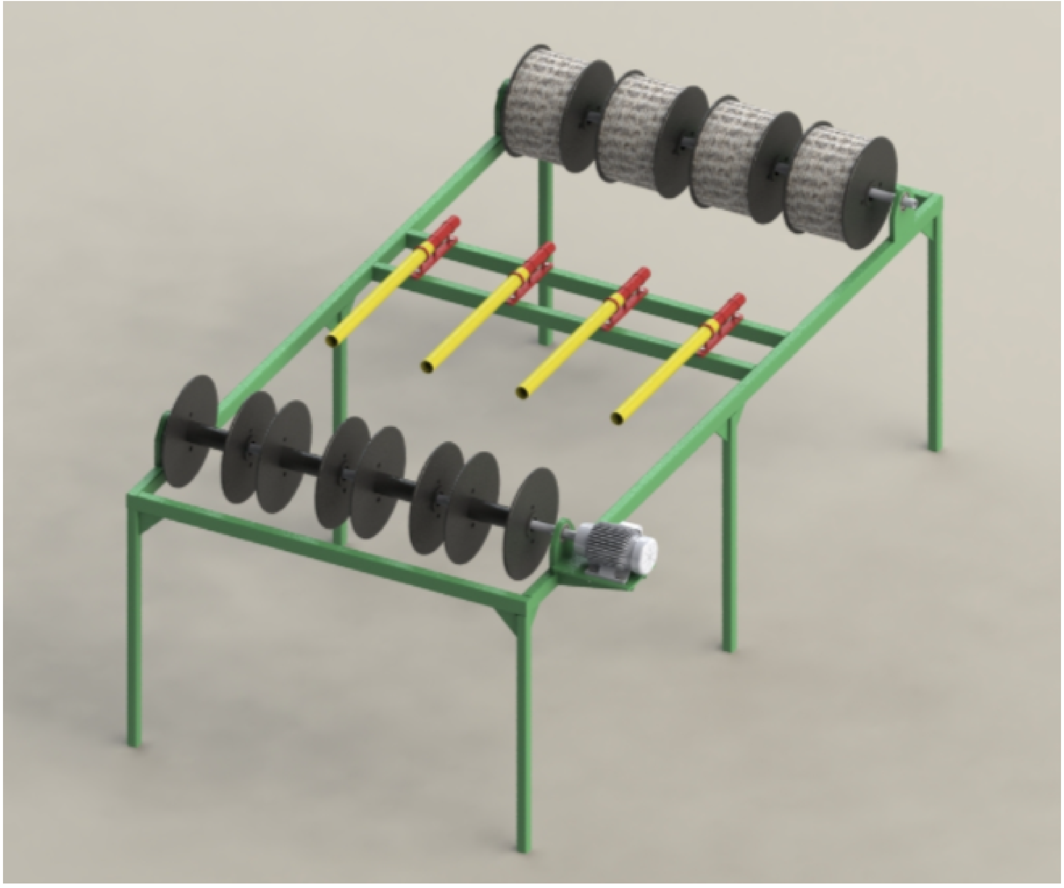
Kunnskap for en bedre verden



EFFICIENT PRODUCTION AND DEPLOYMENT OF KELP LINE

Effektiv produksjon og utsetting av tareline

TMAS3001- Bachelorthesis

May 20, 2021

Preface

This thesis is written at the Norwegian University of Science and Technology (NTNU) in relation to our final year as mechanical engineering students. All three group members have specialization in structural engineering, at the Department of Mechanical and Industrial Engineering. The thesis is written in collaboration with Seaweed Solutions AS, a flagship within seaweed cultivation.

Before reaching out to Seaweed Solutions, the group was determined on working on a thesis related to the marine industry. All the members of the group have an interest and curiosity for the marine business. Diving, fishing, boating, and sailing, are all hobbies we are passionate about. When contacting Seaweed Solutions, we got introduced to a project related to mechanical construction. This was a great opportunity to write a thesis in a field we are genuinely interested in. Seaweed Solutions have given us a lot of freedom to be creative.

Figure 1:
The group (from left to right): Mathias Bueng Gjone, Hermann Peter Schips, Aksel Andrè Wiik Martinsen

We would like to thank our supervisor, Detlef Blankenburg, for advice and close follow-up throughout the thesis. We also want to thank Andreas Lavik and the rest of the team at Seaweed Solutions. They have provided access to a workshop, materials for prototyping, field learning at Frøya, and an office during the writing process. Finally, we would like to thank our fellow students Audun Ryland, Bjørn Spieler, and Ole Jordan for helpful feedback related to the thesis.

Abstract

In a society with an ever-increasing need for energy and food, new ways to meet this demand are being developed. Inspired by a well-established market in Asia, kelp farming has become a growing industry in Norway as well. The large coastal areas prove to be well suited for this form of farming. Since most methods for kelp farming are still based on manual work, the solutions are not sufficiently effective to be able to operate on a large scale. Therefore, the collaborative company in the project, Seaweed Solutions (SES), wants to develop new effective solutions. Through a semester, the group has worked out a concept proposal for how SES and the Norwegian kelp industry can strengthen their competitiveness in kelp farming.

As framework conditions early in the project, the group was asked to develop a new type of kelp line. A kelp line consists of a thick rope with a thin plant-bearing (kelp) line wrapped around it. The task for the group was to develop a machine making the kelp line on a boat and continuously deploy it behind the vessel in low speed. In March, the group was invited to deploy kelp line for testing of new methods. This took place at the premises of SES outside Frøya. In the period before the testing, the group had developed several ideas, and brought the three most promising concepts to the premises of SES. The stay involved testing functional models, concepts, and collecting first-hand experiences from the process. Based on this, a combining method was chosen for further development.

After gaining new insight, the group got a new understanding of the challenge they faced. By repeatedly asking the two questions "how has this been done before?" and "why using this method?" it emerged that the combination of the two lines to the kelp line and the deployment processes from the vessel could be separated. This is considered as an important breakthrough in the project, and through testing and advice, this was considered essential to achieve the goal of increased efficiency. The separation of the process made it possible to coil kelp line on drums prior to the deployment. Using an adapted technique, the drums can be used to deploy several kelp lines from the vessel at the same time. Through tests, the technique has shown great potential in reducing working hours at sea.

Under controlled circumstances, tests have provided estimates that indicate that the new method can be up to six times as effective for deploying, measured against the current method. There are several factors that play a part in the increased efficiency, therefore it is uncertainties regarding the final increase in efficiency. In the absence of quantitative data, the group does not want to indicate a value for increased efficiency, but to conclude that the new deploying method is working. Based on this result, the group points out that the bottleneck for kelp farming is no longer in the launching process, but rather the harvesting and raw material processing.

Before the estimate of the concept's effectiveness can be verified, further testing and quantitative data is needed both from land and at sea.

Sammendrag

I et samfunn med et stadig økende behov for energi og mat, utvikles det nye måter å dekke denne etterspørselen på. Med inspirasjon i et allerede veletablert marked i Asia, har oppdrett av tare blitt en voksende næring også i Norge. De store kystområdene viser seg å være godt egnet for denne oppdrettsformen. De fleste løsningene er ikke tilstrekkelig effektive for å kunne drive i stor skala i Norge, som konsekvens av at de fortsatt baserer seg på manuelt arbeid. Dette gjør at samarbeidsbedriften i prosjektet, Seaweed Solutions (SES), ønsker å utvikle nye effektive løsninger. Gjennom et semester har gruppen jobbet frem et konseptforslag til hvordan SES og norsk industri kan styrke sin konkurransedyktighet innen oppdrett av tare.

Som rammebetingelse tidlig i prosjektet, fikk gruppen som oppgave å utvikle en ny type tareline. En tareline består av et tykt tau med en tynt plantebærende (tare) line surret rundt. Oppgaven var å utvikle en maskin som lager denne tarelinen fortløpende om bord på en båt og settes ut bak båten i lav hastighet. I mars ble gruppen invitert med på utsett av tareliner for testing av ulike løsninger. Dette foregikk ved SES sitt anlegg utenfor Frøya. I perioden før testingen hadde gruppen utviklet flere idéer, og tok derfor med de tre mest lovende konseptene ut til anlegget. Oppholdet innebar testing av funksjonsmodeller, konsepter og førstehånds erfaringer med de aktuelle løsningene. Basert på dette ble en kombinasjonsmetode valgt for videre utvikling.

Etter ny innsikt, fikk gruppen forståelse av utfordringen man sto ovenfor. Ved å gjentatte ganger stille seg spørsmålene "hvordan er dette gjort før?" og "hvorfor med denne metoden?" kom det frem at kombinering av de to linene til en tareline, og utsettingsprosessen fra båten kunne skilles. Dette anses som et viktig gjennombrudd i prosjektet, og gjennom testing og rådgiving ble dette ansett som essensielt for å nå målet om økt effektivisering. Delingen av prosessen gjorde det mulig å spole opp tareline på tromler i forkant av utsettingsprosessen. Ved bruk av en tilpasset teknikk kan tromlene brukes til å sette ut flere tareliner samtidig fra båten. Teknikken har gjennom tester vist stort potensiale for redusert arbeidstid på sjøen.

Under kontrollerte omstendigheter, har tester gitt estimat som indikere at den nye metoden kan være opp til seks ganger så effektiv ved utsetting til sjøs, målt opp mot dagens metode. Det er flere faktorer som spiller inn på effektiviteten og det er derfor usikkerhet om den endelige effektivitetsøkningen. I mangel på kvantitativ data ønsker ikke gruppen å anslå en verdi for økt effektivitet, men konkludere med at teknikken fungerer. Basert på dette resultatet, mener gruppen at flaskehalsen for tareoppdrett ikke lenger ligger i utsettingsprosessen, men heller ligger i høsting av taren og råvareprosessering.

Før estimatet for konseptets effektivitet kan verifiseres, er det behov for kvantitativ data fra videre testing på både land og ved utsetting til sjøs.

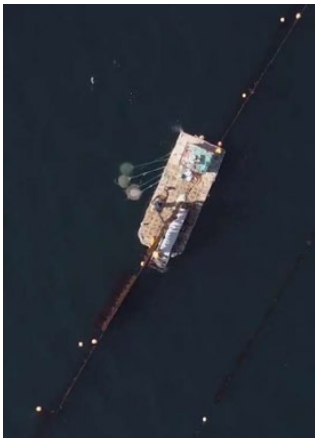
Words and phrases

Word	Description
Carrying rope	A Ø16mm rope used as the main rope for kelp growth
Deployment	The process when deploying at sea
Drum	A spool where rope can be coiled on
Handling of kelp spores	This statement means that optimally, the kelp spores should not be touched nor scrape anything.
Kelp lines	Combined and fertilized product
Kelp spores	Kelp until it is fully grown, then referred to as kelp
Seaweed Solutions AS	The partner company, referred to as SES
Seeding line	Ø1.4mm fertilized line , grown in a laboratory
Seeding spool	The spool the seeding line is coiled on
Period	The interval of time between successive occurrences of the same state in a cyclic phenomenon, related to the seeding line coiled on the carrying rope.

Table 1: Words and phrases

Department of Mechanical and Industrial Engineering

BACHELOR THESIS SPRING 2021
AKSEL WIIK MARTINSEN; MATHIAS BUENG GJONE HERMANN PETER SCHIPS;



EFFICIENT PRODUCTION AND DEPLOYMENT OF KELPLINE
Effektiv produksjon og utsetting av tareline

Norway has set a goal of upscaling the kelp production. Today´s production is too expensive and inefficient to be scaled up. The thesis will cover the design of a machine which will assemble a line fertilized with kelp and a carrying line, making the process at sea more efficient.

The thesis covers the following points and is carried out in cooperation with SeaWeed Solutions, a Norwegian company based in Trondheim:

1. A brief analysis and description of product, technology, and market
2. Development of necessary specifications as a basis for further work
3. Development, evaluation, and presentation of alternative concepts
4. Selection, further detailing and refining the most promising concepts
5. Development of structure, design, and documentation of selected components
6. Production and testing of functional models of selected components
7. Evaluation and presentation of the results
8. Evaluation of methodology and results compared to the learning objectives

The assignment shall actively use a project journal.

The work must be risk assessed. Risk assessment is an ongoing documentation and must be done before starting any activity that MAY be associated with risk.

The thesis must include a signed assignment text, a summary in English and Norwegian, conclusion, bibliography, and table of contents. When preparing the thesis, the candidates must emphasize making the text clear and well written. In the assessment of the thesis, great emphasis is placed on the results being thoroughly processed, that they are presented in a tabular and/or graphical manner and discussed in detail.

Contact person: Andreas Quale Lavik, Seaweed Solutions

Detlef Blankenburg
Thesis advisor

Contents

PART I

INTRODUCTION

1 Description of the thesis

The thesis deals with the development of an efficient method for the production and deployment of kelp line for offshore cultivation farms. It is written in collaboration with Seaweed Solutions AS, which is one of the leading producers of seaweed in Europe. From their search for bottlenecks, there is now a basis for the statement that efficiency within production and deployment would make fertile ground for the seaweed industry expansion. The task given at the beginning was to develop a machine for the production of a deployable kelp line. In order to accomplish this, we found it necessary to look into the entire cultivation process - from the kelp being only samples of a mother plant to the end stage, harvesting. Looking at the entire process has been considered to be essential for the development of a proposal that meets the requirements.

1.1 Background for the task

Seaweed cultivation is a growing industry with the potential of relieving the planet's demand for animal and plastic-based products. This includes demands for food, feed, materials, and energy for a growing global population. Marine industries like oil, transport, and fishing have many unfavorable effects on the environment. As far as we know today, the seaweed cultivation process has very few meaningful negative effects on the environment compared to the positive ones, and kelp farms are often seen with flourishing life around them. To be able to utilize seaweed as a resource there is a great need for expansion and streamlining. Norway, with one of the world's longest tempered and productive coastlines, is well suited to take a leading role.[1] [2] [3]
A video of Seaweed Solutions in Financial Times (click for link), is worth watching to get a better understanding.

1.2 Seaweed Solutions AS

Seaweed Solutions was established in 2009, and for the past 10 years, the team has built knowledge and experience in all stages of seaweed cultivation. Their vision is to enable large-scale ocean farming of seaweed. Their main office is in Trondheim, where they have their research lab and hatchery. The farm is located in the ocean close to Frøya, an island out in the sea along the Trøndelag coast. The farm on Frøya has been used to test and develop new methods for the large-scale cultivation of seaweed. The workers with whom the group has collaborated have mostly been marine biologists. [4]

1.3 Final concept

It is important to emphasize that the concept is a proposal for a process, and it is not detailed or dimensioned to a great extent.

The concept involves two separate processes, combining and deploying. The combining contains a process where a carrying rope and a seeding line are combined on a land-based facility. The kelp line will be coiled onto drums. The combination can be done on several drums simultaneously, by being connected on the same shaft. This will streamline the work at land. The drums will be transported to a farm where they can be deployed.

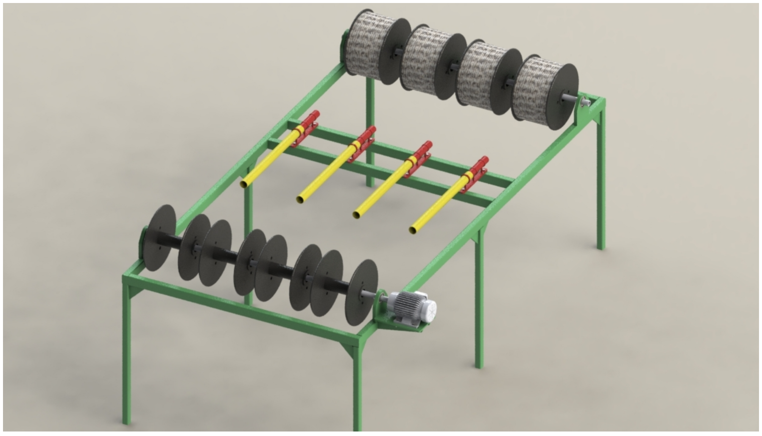


Figure 2: Conceptual illustration of combining construction

The drums from the combining are used for deploying. By placing drums on a rack, the drum will be uncoiled directly to the farm. Deploying several kelp lines at once will increase the length of ropes that can be deployed within a given time. It will also significantly reduce the number of times needed to stop the boat.

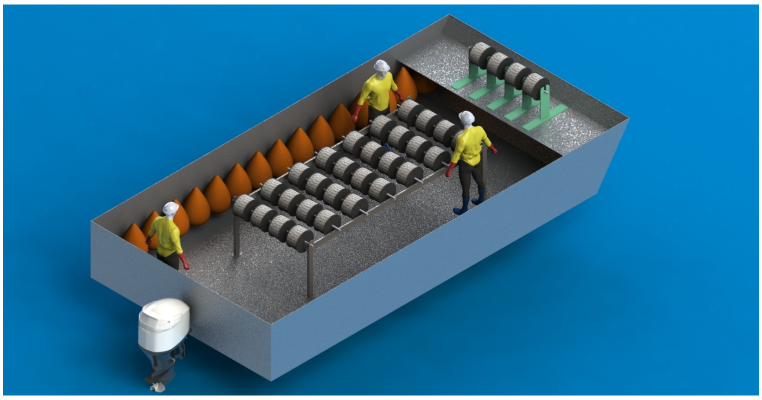


Figure 3: Conceptual illustration of boat during deployment

Through testing and development, a potential for streamlining the deployment process was found. While working time on land is increased, the working time and load at sea are seemingly reduced compared to the method used today.

2 Disposition of the thesis

The thesis is structured to guide the reader through the project. It should be possible to understand the decisions made by the group. The sections of the thesis and their contents can be seen in Table 2.

Chapter	Content
I Introduction	Introduction to the purpose and motivation for the thesis.
II Conceptual framework	Description and analysis of the process and presenting the requirements for the new product development process (NPD)
III Development	The section where different concepts are generated, developed, and compared with the requirements
VI Results, discussions, conclusion and further work	Results, discussions and conclusion of the process. Further work is also presented
V Methods and theory	Methods for how the procject has been executed and relevant theory
VI Bibliography	Relevant attachments, and sources used in the thesis

Table 2: The disposition of the thesis

PART II

CONCEPTUAL FRAMEWORK

3 Introduction and analysis of the industry

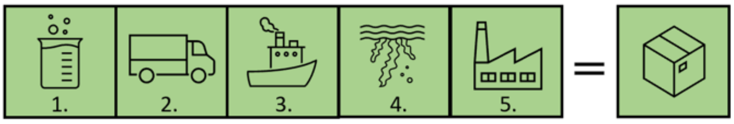
This chapter will be a brief introduction to the seaweed industry and the methods used for seaweed cultivation. The introduction is largely aimed at Seaweed Solutions' way of cultivating. It will also explain the demand in the industry related to the thesis.

Figure 4: Sugar kelp in an ocean farm

3.1 Introduction to kelp farming

Seaweed farming is an international industry. Today Asia is producing over 99 percent of the global farmed kelp. In other words, Norway is considered a small contributor from a global point of view. Most of the production in Norway is located in the areas of Vestland, Nordland, and Trøndelag. The Norwegian coast is considered very well suited for kelp farming. The kelp industry in Norway is still at an early stage, but since Norway has established solid expertise within the aquaculture industry, there is predicted that the industry will accelerate rapidly over the next decades. When explaining "Today's process", the cultivation is done with kelp species which are most desirable to grow in cold ocean climates. In Norway, the process varies from south to north of the country, due to different climates. Along the Norwegian coast, there are many different seaweed farmers. The methods tend to vary, the reason for this is that small changes in ocean climate can be dramatic for the cultivation of kelp. In collaboration with Seaweed Solutions, the focus has been to develop a process fitting the ocean climate at their ocean farms, but the technique should be possible to adapt.

To explain today's cultivation process in a general manner the process is divided into the following stages: breeding, transport, deployment, harvesting, and processing. The end result of these stages is kelp, ready to be sold. Each stage of the cultivation process is described under its own subsection in the following chapter. The methods described are a brief intro to Seaweed Solution's cultivation process.



1. Breeding 2. Transport 3. Deployment 4. Harvesting 5. Processing

Breeding
The first part of the process takes place in a laboratory. Zoospores are collected from mother plants that live in artificial water pools. The zoospores grow up to become sporophytes. The sporophytes will be referred to as kelp spores, and adult sporophytes (full-grown) will be referred to as kelp. These spores are then sprayed onto a medium, usually thin ropes or lines. Today's method uses Ø6mm ropes for breeding. These ropes are coiled around a pipe to create as much surface as possible. By applying the kelp spores to thin ropes in this manner, the number of kelp spores bred in the lab expands significantly. These lines are stored in salt water pools with the right climate for good growing conditions. After 6-8 weeks the spore has grown big enough to be placed in the ocean. At this point, they are ready to enter the next process before deployment at the farm.

Figure 5: Kelp spores on Ø6 mm ropes

Transportation
As the breeding facility is not located in direct proximity to the kelp farm, it needs to be transported to the farm. The artificial pools the kelp is bred in, will not be a part of the transportation because of the sizes of the pools. This is considered a critical part of the process because the kelp spores are being moved from their ideal climate. The kelp spores can survive in an air-tight container for some time as long as it's not exposed to sun, wind, and temperatures above 17 degrees Celsius. In general, it is wished to deploy the kelp spores within 24 hours after being transported from the laboratory.

Deployment

Deployment of kelp spores in the ocean is a time-consuming part of the process. The deployment is season and weather-restricted. This means the deployment period often is short, and it is essential to deploy efficiently to be able to cultivate big volumes of kelp. Today Seaweed Solutions deploy the kelp ropes in a ladder formation 6. This is done by tying 15 meters stretches of Ø6mm kelp rope to the framework of the farm. The kelp ropes are deployed across two framework ropes. Each 15-meter kelp rope is tied to the framework on both sides, this is done by manual tying. The estimated deployment rate is estimated to be approximately 0.5-1.0 km/h.

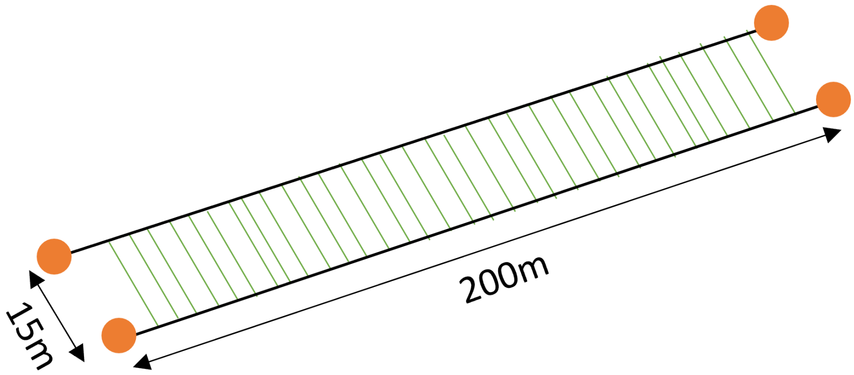


Figure 6: Illustration of today's deployment formation, green lines illustrates kelp lines.

The boat Seaweed Solution uses today for deployment can be seen in Figure 7. The boat is 4x8m.

Figure 7: Boat used for deployment

Harvesting
The way the kelp lines have been deployed months ago are now determining how efficient the harvesting can proceed. Harvesting is done by cutting the kelp ropes on one side and dragging the kelp ropes onto a harvesting vessel. The ropes are now weighing a lot more, the kelp spores have now grown up to 4 meters long. Today's method provides about 3-6 kilos wet weight of kelp per meter rope. The kelp is heavy and space demanding when still wet, and it is needed a support vessel to transport the kelp to land in an efficient way.

Figure 8: Harvesting at Frøya by Seaweed Solutions

Processing
After harvesting it is essential to get the kelp to a factory, where it can be dried before it rots. These factories are often fish and shellfish processing factories that have the potential to be used for kelp processing. The kelp can either be frozen or dried. After the kelp is processed it can be sold to consumers.

Figure 9: Processing of kelp at HitraMat

3.2 Evaluation of today's method

Even though SES as a company is over a decade old, there are many parts of the cultivation process which is not optimized. Due to the need for research over many years, it tends to take time. The method used today is characterized by a lot of losses. To be able to ensure further expansion of the industry, it is necessary to point out the most obvious bottlenecks in the process. Manual labor is a common feature in the stages of production. It is especially the manual labor at sea that sets the limits for further expansion. It is easy to say that the production should be automated in all stages of production, but this is not a realistic goal in the short term. Streamlining the biggest bottlenecks of the industry is a much more affordable goal.

3.3 Development prior to the thesis

Seaweed Solution wishes to leave today's method in favor of a more efficient method. To be able to increase both breeding capacity and efficiency at sea, SES has looked into decreasing the thickness of the rope the kelp spores are bred onto. From breeding on 6mm rope to breeding on a 1.4mm line (see Figure 10). This method will significantly increase the total length of the kelp line produced in the laboratory.

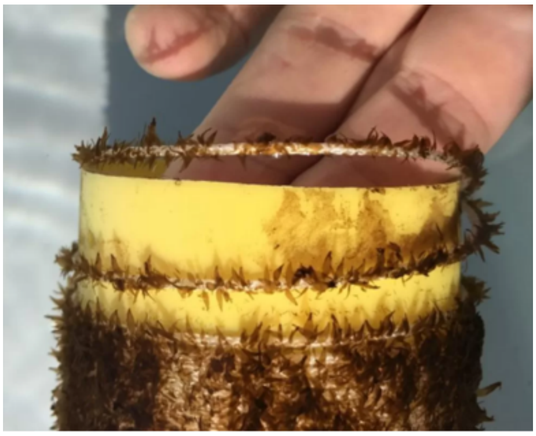


Figure 10: Kelp spores on a thin kelp line, ready for combining

The 1.4mm line provides opportunities and creates new challenges. The line is too thin to be placed in the ocean by itself, there are mainly two challenges; the kelp needs a bigger medium to grow onto, and the tensile strength of the line is too low to ensure safe growth conditions. The thin line must be combined with a thicker rope to ensure its survival in the ocean. The thicker rope will work as a medium for the kelp to grow onto, and it will be strong enough to handle the tensile forces applied to the rope. This introduces us to the demand for a new stage in the cultivation process. This stage is called *the combining stage*, which will present how the line and the thicker rope are to be combined. Using a thick rope combined with the thin line it will be possible to deploy much longer distances with ropes before tying to the framework. This way of breeding was visioned from Seaweed Solutions prior to this project and is not a part of the group's development.

Figure 11: Illustration of Combining as the new stage in the cultivation process

3.4 Basic demands for the task

Combining was presented in the previous chapter, but the method is not developed. It is in Seaweed Solution's interest to develop a method for combining which will benefit the deployment and harvesting process. To summarize this chapter, the aspects of the process which is relevant to the thesis are presented - the framework conditions. Growing kelp spores on thin seeding lines in the lab is an efficient way of scaling up the breeding process, and deliver bigger quantities of kelp spores for combining. This up-scaling of the breeding stage demands development of a new method for combining and deploying in the sea. Seaweed Solutions desire is that this new method will help to streamline and reduce costs related to the cultivation. This desire is what underlies the thesis.

4 Framework conditions

Prior to the development process, different framework conditions for the task were presented. The framework is referred to as the physical boundaries, which were set before the development process started.

4.1 Framework in the sea

Seaweed Solutions have farms on Frøya, and these are set as a standard size. A draft of the farm can be seen in Figure 12. The farm consists of a framework of ropes, floating elements, and anchors. This foundation creates the boundaries of how much kelp line it is possible to deploy on the farm. One farm measures 400 meters times 400 meters. This square is divided into four smaller squares measuring 200 meters times 200 meters. The focus has been deploying across these 200 meters squares. At each end of the deployed kelp lines, a connection to the framework of the farm is needed. It is necessary to have a floating element after 50 meters of kelp line deployed.

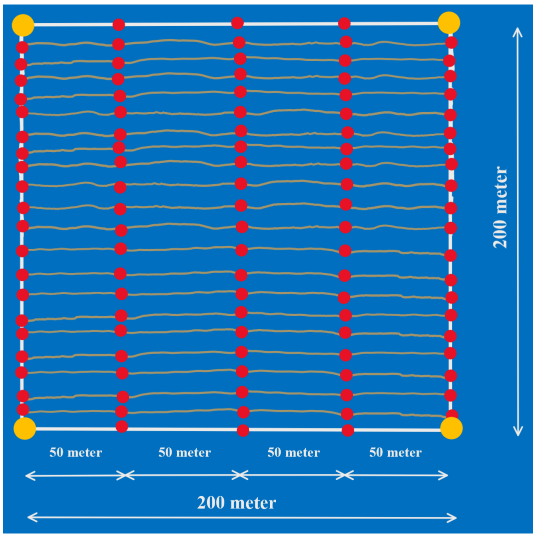


Figure 12: Simplified illustration of a 200*200m farm:

1. Red dots = Floating elements
2. Corner buoys = Anchoring to seabed
3. Brown horizontal lines = kelp lines
4. White line = Permanent ropes keeping the farm together

In Figure 12, the brown kelp lines and the red floating elements inside the square will be deployed and harvested. The frame of the square is permanently placed in the farm.

4.2 Ropes

Ropes and lines are an essential part of seaweed cultivation. They create the foundation for the kelp spores to attach and grow on. Some of the critical factors are durability, elasticity, and buoyancy. Some ropes contain chemicals that make it impossible to grow kelp onto them. As a result, SES has decided which ropes and lines to use; the seeding line and the carrying rope.

Carrying rope
The carrying rope, where the kelp set roots, is a 3-end twisted Ø16mm polyester rope. The rope is a dimensional part of the cultivation and must withstand the forces from the weight of the kelp and the rope itself. Currents and strong winds, create high tension in the ropes, demanding careful consideration related to the rope's capability.

Figure 13: Carrying rope ready for test deployment

Seeding line

The seeding line is a thin polyester line of Ø1.4mm, that combined with the carrying line, make up the kelp line. The seeding line contains quantities of tiny kelp spores that will grow onto the carrying rope. This line is very thin and does not tolerate big tensile forces. It is important that it does not become a bearing part of the kelp line. As soon as the kelp has set roots in the carrying rope, the seeding line no longer has a purpose.

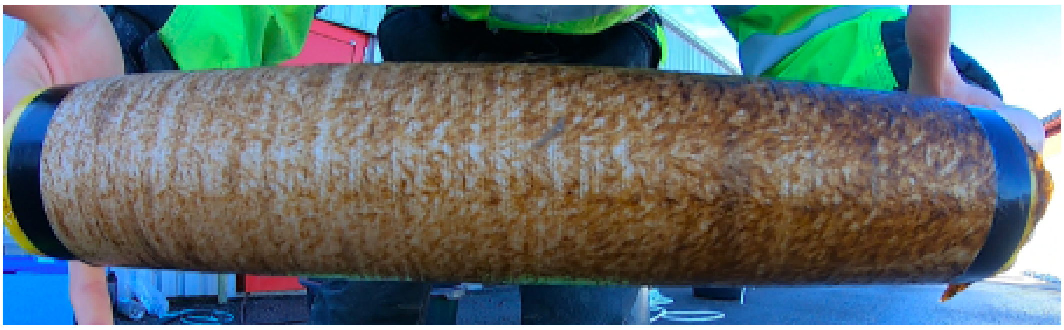


Figure 14: Seeding line spun tightly around a PVC-pipe (Seeding spool)

4.3 Seeding spool

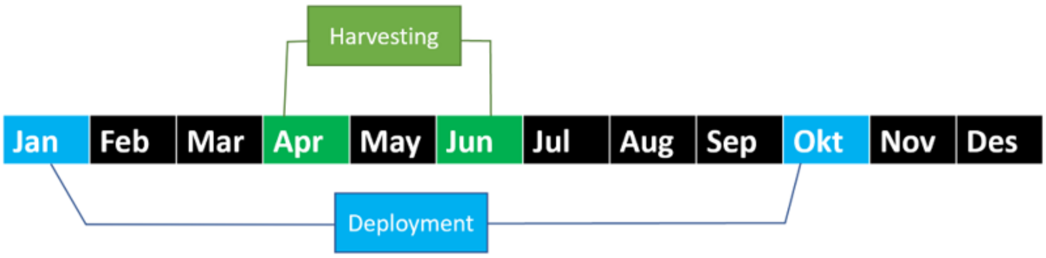
The laboratory and breeding facilities are limited. The seeding line is spun onto a PVC pipe to make the most out of the surface of the line, without overlapping. The kelp spores are sprayed onto the seeding spools. PVC pipes are often used, due to their suitable material properties. It neither dissolves in saltwater nor affects the kelp spores and it is cheap compared to aluminum or stainless steel. The desired dimensions for the seeding spool set by SES are 700mm long and a diameter of Ø50mm.

Figure 15: Seeding spool without the kelp spores(Pre-laboratory)

4.4 Biological

The biological framework represents the boundaries set for cultivation on Frøya. Research and development of marine conditions is an important subject for SES. Due to working in this environment, considerations regarding the topic must be taken. SES are cultivating Saccharina latissima (Sugar kelp) and Alaria esculenta (Butare).

Seasons
To ensure a good crop from the cultivation, it is essential to deploy and harvest at the right time of the year. For deployment, October and January are set as the desired months, and six months later, April and June are the desired months for harvesting. The result is two months for deployment and two months for harvesting.



4.5 Materials

In seaweed farming the operating environment is saltwater, therefore materials need to be corrosion withstanding. Seaweed farming is a part of the food industry, and materials in direct contact with the kelp also need to meet requirements set for contamination. Some standard materials used for similar applications within aquaculture and fishery are aluminum alloys, AISI316, AISI304, and PVC-plastics. The ropes will be made from nylon, a polymer that also is frequently used within marine environments.

5 Requirements

The seaweed cultivation process has many aspects, and some of them have been presented in the introduction. Throughout the project, new aspects have appeared consecutively, so the development of the requirements has been dynamic. The requirements for the NPD process are developed from testing and in cooperation with marine biologists from Seaweed Solutions.

The basis for the requirements is to make a concept, which is **increasing the efficiency**, and facilitate **upscaling**, resulting in **increased earnings**, while **reducing production cost**. Streamlining has been in mind during the entire NPD process.

Overview of the requirements
The complexity of the different aspects in a cultivation process is illustrated in Figure 16. The aspects regarding combining and deployment are represented in the mind map and are presented to provide insight into how the aspects have been explored.

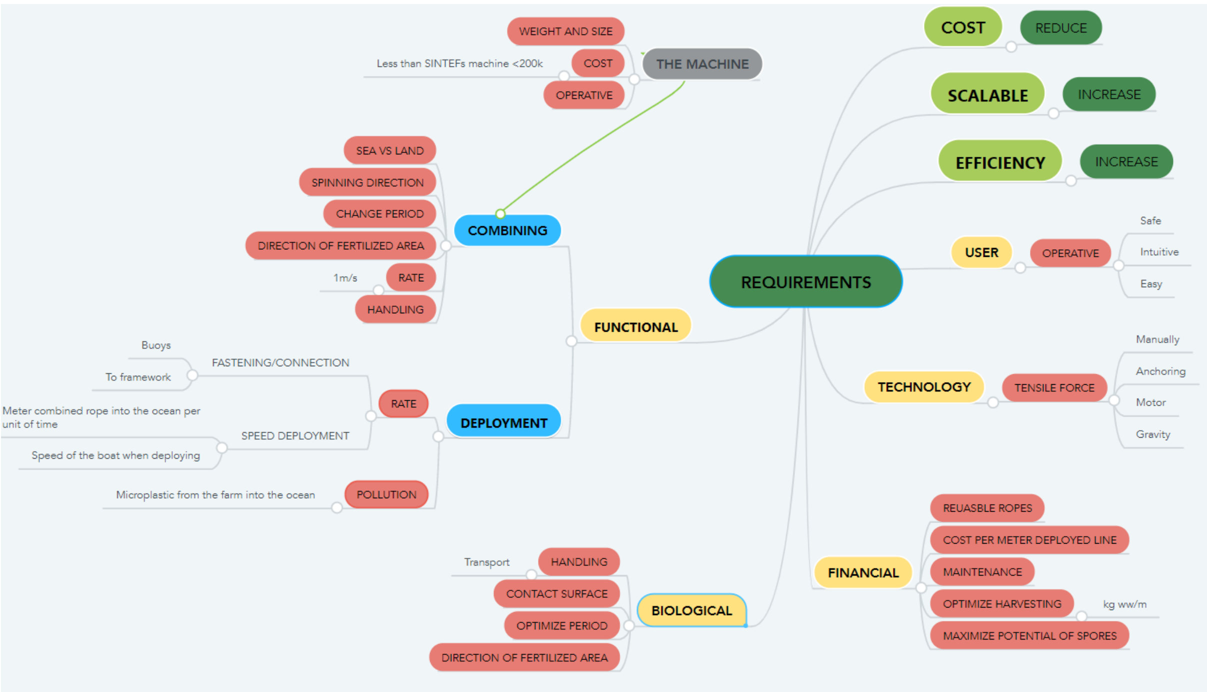


Figure 16: Mind map of the complexity

The final requirements are presented in table **??**, and makes the foundation of what will be important for the choices made during the NPD process. They will be used to evaluate different concepts and ideas. In chapter 20, the requirements are discussed.

No.	Name	Description and goal
01	**Rate**	*Meter kelp line deployed per second* **Goal: Singular combining with a rate of** $>1\,\mathrm{m/s}$ **Goal: Singular deployment with a rate of** $>1\,\mathrm{m/s}$
02	**Contact surface**	For making it possible for the seaweed to grow on the carrying rope, it is necessary to have a contact surface between the seeding line and the carrying rope. **Goal: The seeding line should have continuous contact with the carrying rope**
03	**Handling**	It needs to be as little handling of the kelp spores as possible **Goal: Minimum amount of handling of the kelp spores through the process**
04	**Operative**	The combination and deployment should be designed in a manner which makes it intuitive, easy and safe to use. **Goal: The combination and deployment should be simple and safe to use**
05	**Connection**	Quick connections between ropes, floating elements, and to framework in the sea **Goal: Reduce time used for connecting**
06	**Harvesting**	Facilitate for low faulty production, increase production volume and a less time-consuming harvest of kelp. **Goal: Facilitate for current method of harvesting**

Table 3: Requirements

PART III

DEVELOPMENT

6 Development overview

The development process has been comprehensive and interdisciplinary. The process has involved different methods and techniques before the final concept was reached. Throughout the development process, several crucial points, where decisions had to be made, were necessary before the final concept was presentable. The most important crossroads are divided into four stages to make it clear.

The four stages will review the process diagram described in Figure 17. All the stages start with a need and result in a conclusion. The conclusions in each stage will open the development of the next stage through a demand. The final concept will be a result of the four stages.

The stages of development:

1. Combining technique
2. Operating conditions
3. Function parts
4. Deployment method

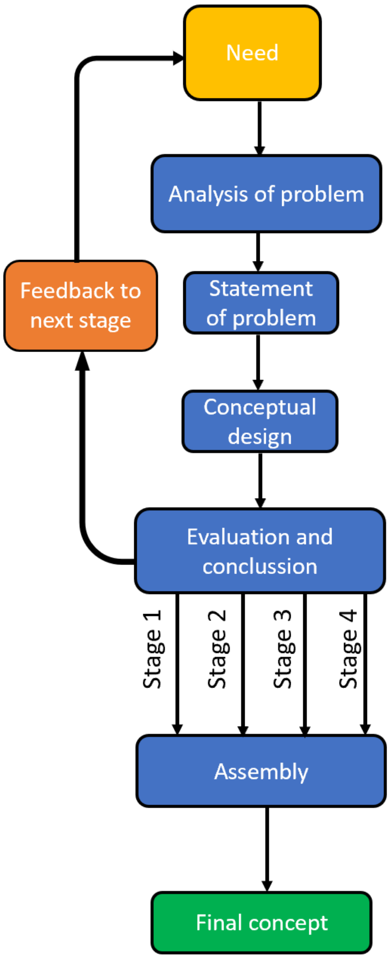


Figure 17: Process diagram of the development

7 Combining

The first stage of the development contains the initial task SES presented. The challenge was how seeding lines could be combined or attached to a carrying rope. This chapter includes brainstorming, concept generation, evaluation, and selection of a combining concept. In Figure 18 are a mind map of stage 1 and different aspects related to combining.

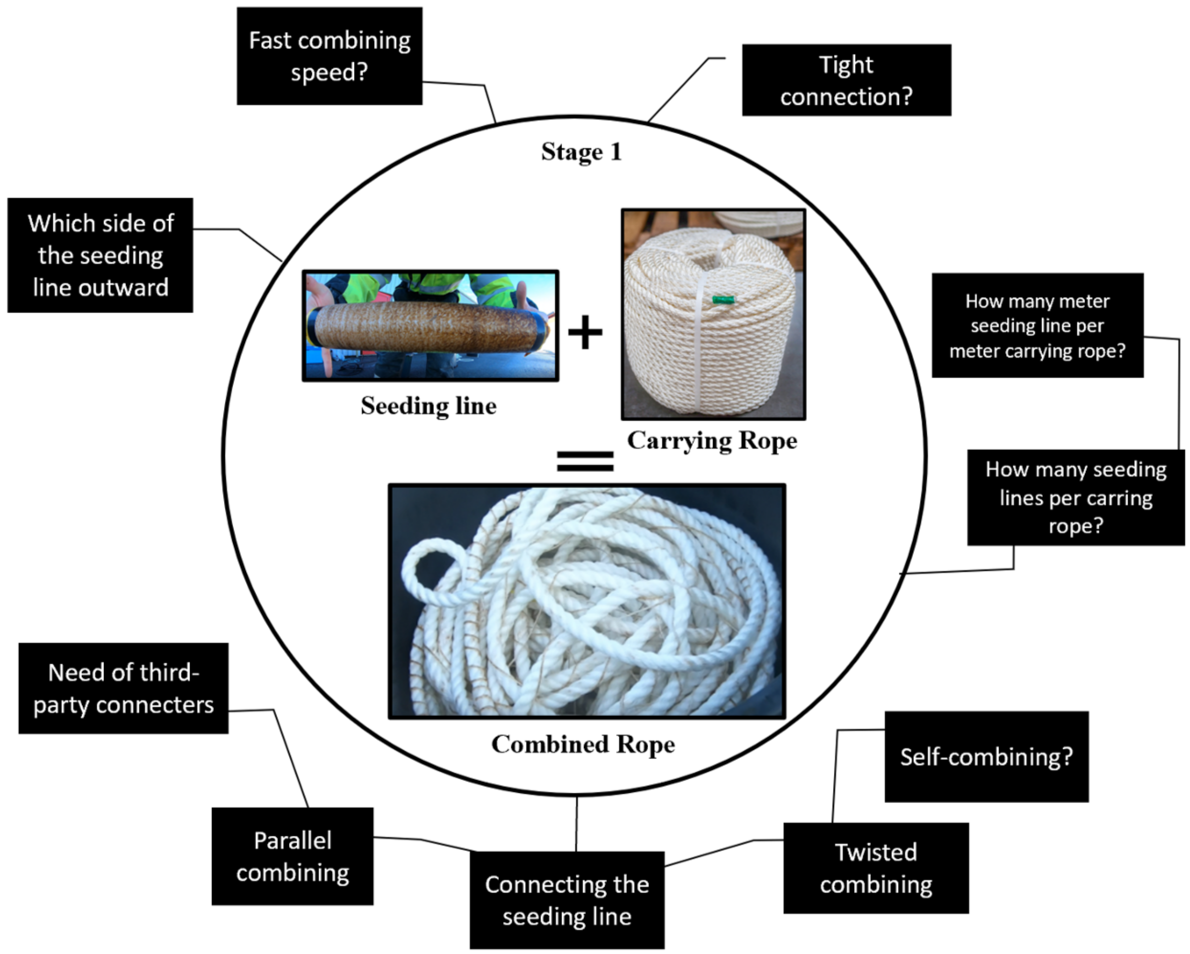


Figure 18: Brainstorming of combining

7.1 Concept generation

The first step of concept generation involved exploring the fundamentally different methods of combining the seeding line with the carrying rope. A draft can be seen in Figure 19.

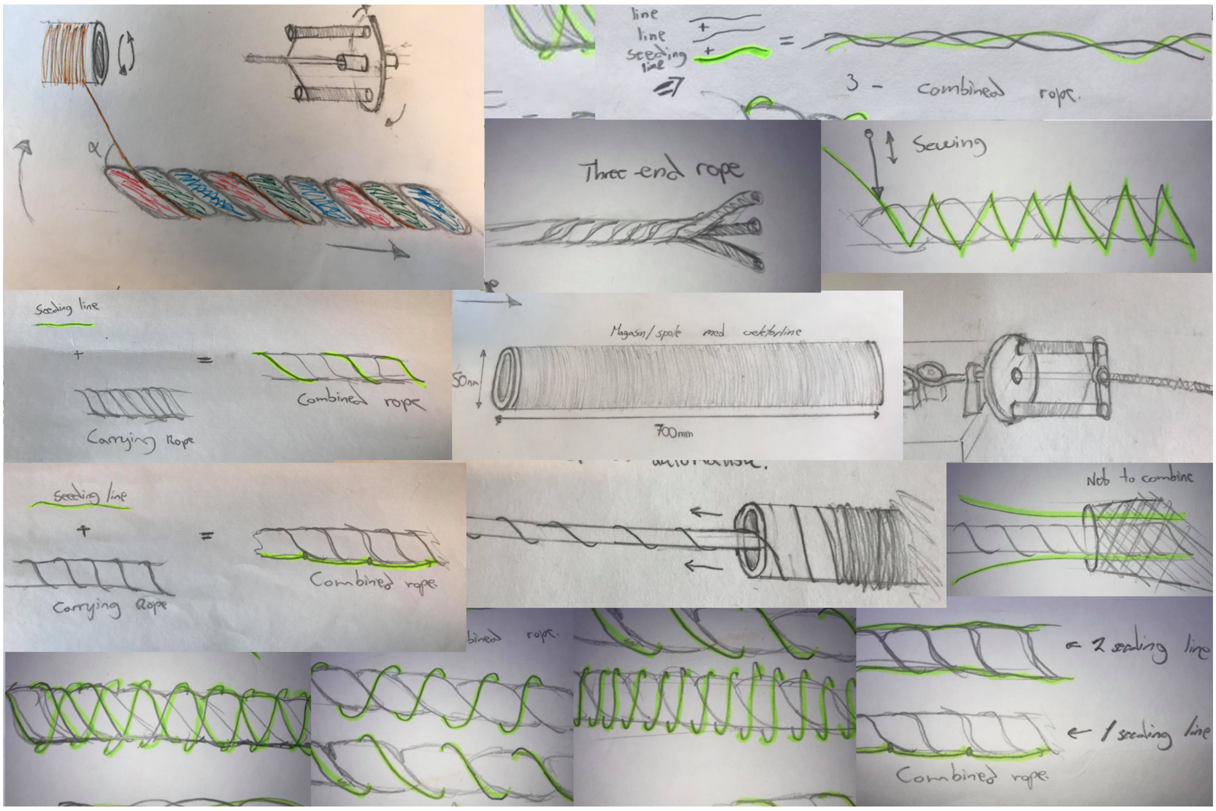


Figure 19: Excerpt from concept drawings

From the brainstorming and concept generation, three methods were brought forward for further development. Each method has numerous different variations, which are seen as appropriate ways of combining. The concepts consist of two different ways to coil the seeding line around the carrying rope and one method of attaching the seeding line in parallel. There are other ways, but these are the most sensible to present. Each concept has a brief explanation of its function, including sketches and a list of positive and negative properties.

7.1.1 Revolver

The revolver method resembles a revolver gun, and therefore its name. It consists of one or more seeding spools mounted to a plate revolving around the carrying rope, while the seeding line is connected to the carrying rope. The carrying rope will be placed in the center of the rotation. At the same time, the carrying rope is being pulled through. The result is a transfer of the seeding line from the spool to the carrying rope. The seeding spool will need to rotate around its own axis to be able to feed the seeding line over to the carrying rope. The result should be a seeding line coiled around the carrying rope, and the outcome is called the kelp line. An excerpt of the different variations can be seen in Figure 20.

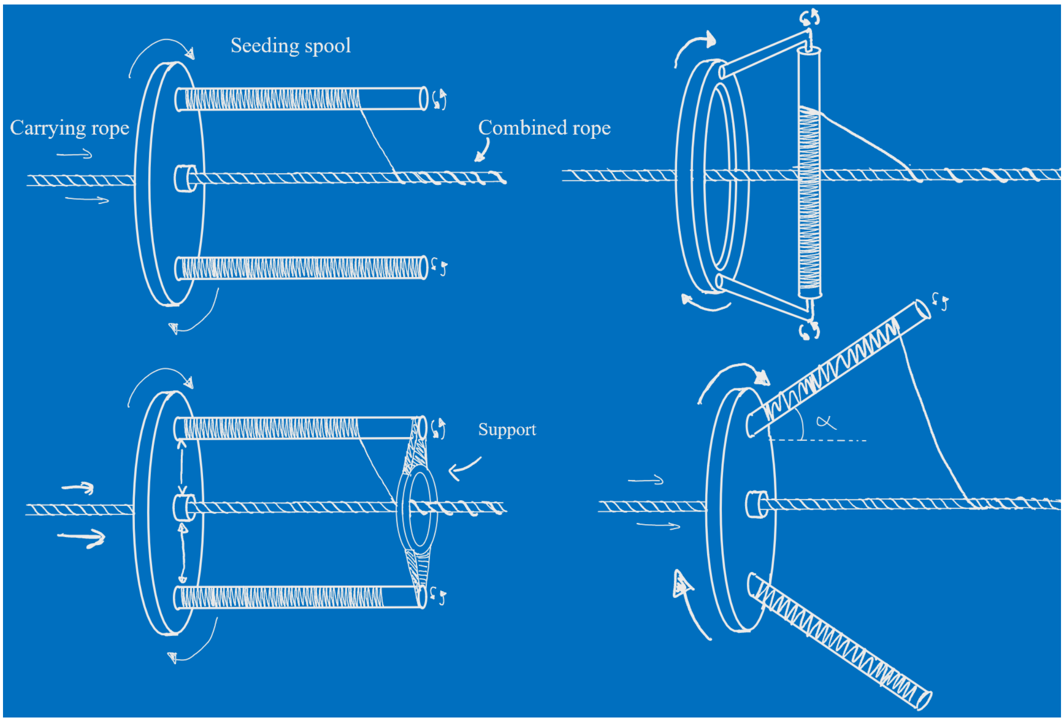


Figure 20: Revolver drafts

Positive

- Several seeding spools could be mounted.
- The rotation of the mechanism could be adapted to provide desired period.
- A resistance could be mounted to the spools, creating a better contact surface.

Negative

- Expensive to construct and maintain.
- Components moving at high speed are not desired for the operating conditions.
- Mechanism must be stopped each time a seeding spool is empty.

7.1.2 Extractor

The extractor simply transfers the coiled seeding line to the carrying rope. The seeding line is coiled around the seeding spool prior to production, and by using the geometry of the seeding spool it is possible to transfer this over to the rope. Since the spools are hollow it is possible to pull the carrying rope through the spool and attach the seeding line to the carrying rope. While pulling the carrying rope through the seeding spool, the seeding line will continuously be fed over to the rope. When a seeding spool is empty, the carrying rope must be pulled to an end, to be able to remove the spool. To combine more seeding lines without cutting the rope, seeding spools can be put in series. See Figure 21. The extractor technique is used in the seaweed industry. However, it is assumed that not all variations of the method have been unfolded, and are therefore presented as a concept for further development.

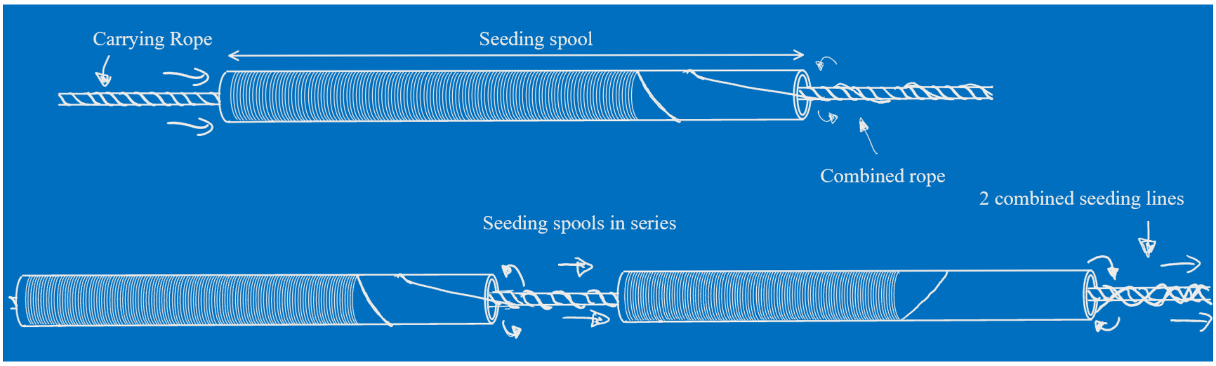


Figure 21: Draft of the extractor

Positive

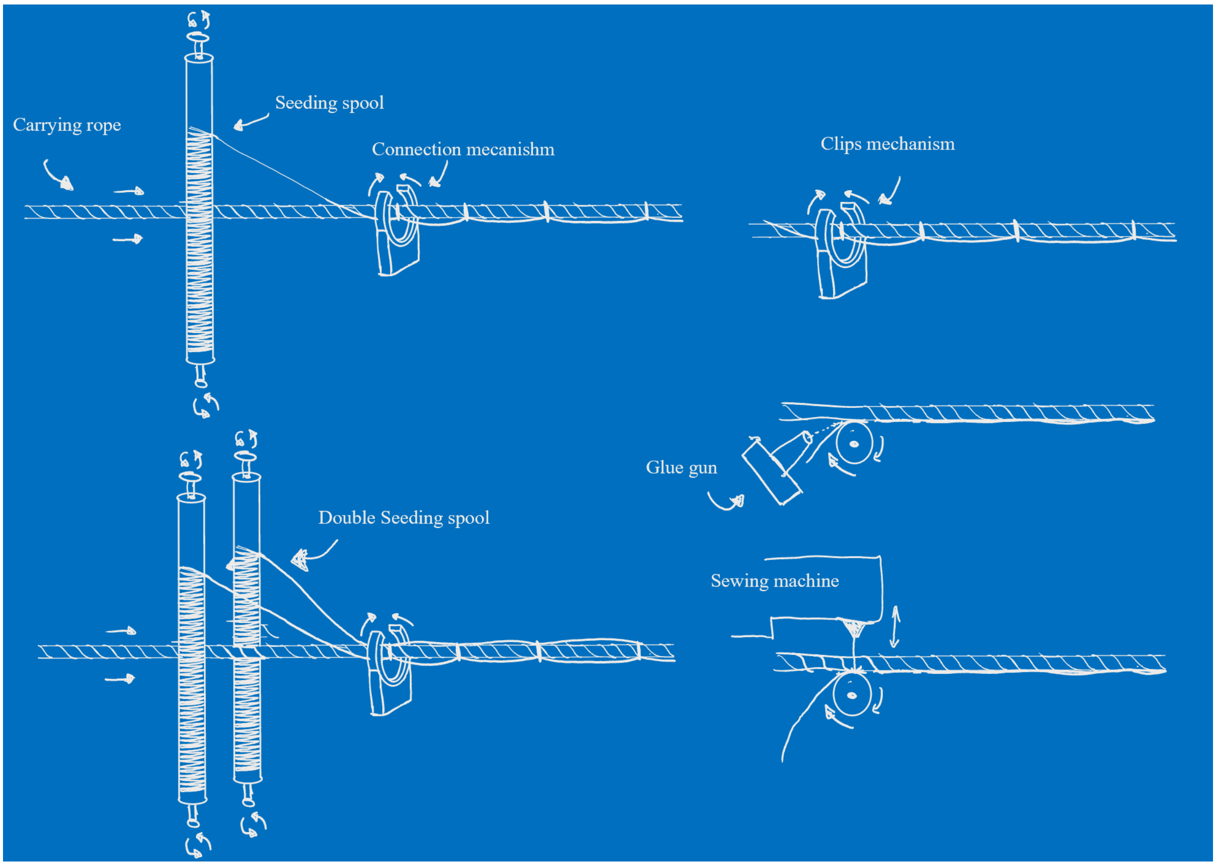
- Simple, requires minimal components.
- Could provide high production speed, does not depend on moving parts.

Negative

- Seeding spools cant be changed without ending the carrying rope, since the rope is pulled through the spool.
- Difficult to change periods.
- Since the diameter on the spool is bigger than the rope the seeding line could combine with low contact surface.

7.1.3 Parallel

An alternative is to completely avoid the coiling process, by attaching the seeding line in parallel with the carrying rope. This could be done with different connection mechanisms. The seeding line could be doubled if it is necessary for better growth. A draft of the method is presented.



Positive	Negative
• Simple, with few components (apart from the connection mechanism) • Easy to variate number of seeding spools in use. • Low handling of the seeding line, because of no coiling.	• Without a decent connection mechanism the seeding line will not have a good contact surface. • Can only increase the amount of kelp spores by applying another seeding line. • Without a fast connection technique, the rate would be slow.

7.2 Evaluation and comparison

An evaluation and comparison of the concepts are essential to decide which to use for further development. To get an insight into the potential and concerns related to each concept, it is important to unfold all the properties. Building and testing function models of the concepts have been a big part of the research. Conclusions and assumptions related to the concepts are based on experience and observations from the tests. In the following chapter, each concept will be presented with a brief review and a list of potential and concerns related to the requirements. The relevant requirement is placed in [brackets]. Aspects of the concepts considered neutral, will not be mentioned, since it does not contribute to the comparison.

Revolver

Function models were built with plywood sheets and PVC pipes, and one was brought to Frøya for testing. The combining was done at the dock and deployed by hand at sea.

Figure 22: Pictures from workshop, combining and deployment with the revolver

Potential

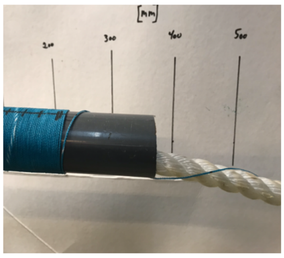
- Easy to change period by increasing the speed of the plate [06]
- The tension on both seeding line and carrying rope can be customized to achieve the desired contact surface [02]
- Close to no contact on the seeding spool results in minimum handling [03]

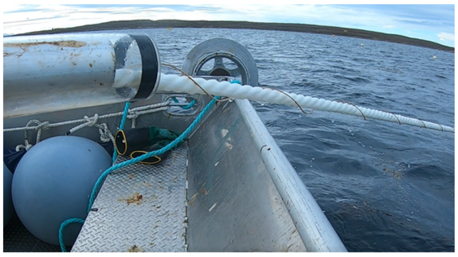
Concerns

- It will be difficult to achieve a decent combining rate[01]
- The machine will need fast moving parts, not ideal for safety[04]
- The fast rotation may cause damage to the kelp spores[03]

Extractor

The Extraction concept needs limited components to work properly. Many test variations were done at the workshop. A function model was used for combining and deployment of kelp spores at Frøya. The combining and deployment were executed at the sea.





Potential

- Can deliver a high rate of combining [01]
- Minimum of components and movement of the seeding line result in low handling[03]
- Simplicity of the mechanism makes the concept intuitive, reliable, and safe to use[04]

Concerns

- Low tensile force on the seeding line during combining can create loose contact surface [02]
- Difficult to manipulate the periods into desired lengths, may not be ideal for growth[06]

Parallel lines

The parallel lines were tested with different connection mechanisms; knots, strips, and a C-ring machine. The machine bends metal into rings with great force, the rings were placed around the seeding line and the carrying rope. The seeding line was combined with the carrying rope on land, and deployed by hand at the farm.

Illustration

Potential

- Can provide a high rate of combining with the right fastening mechanism[01].
- Handling can be minimized since there are few components in touch with the seeding line during combining [03].

Concerns

- Without continuous contact surface will the movement between seeding line and carrying rope limit growth in the sea [02].
- There is a lot of uncertainty associated with the development of a suitable fastening mechanism [05].
- Movement of the kelp line in the ocean will create tension on the seeding line, there are concerns if the seeding line may tear in bad weather [06].

Eventually, the concepts are presented in an evaluation matrix based on the requirements, see Figure 23.

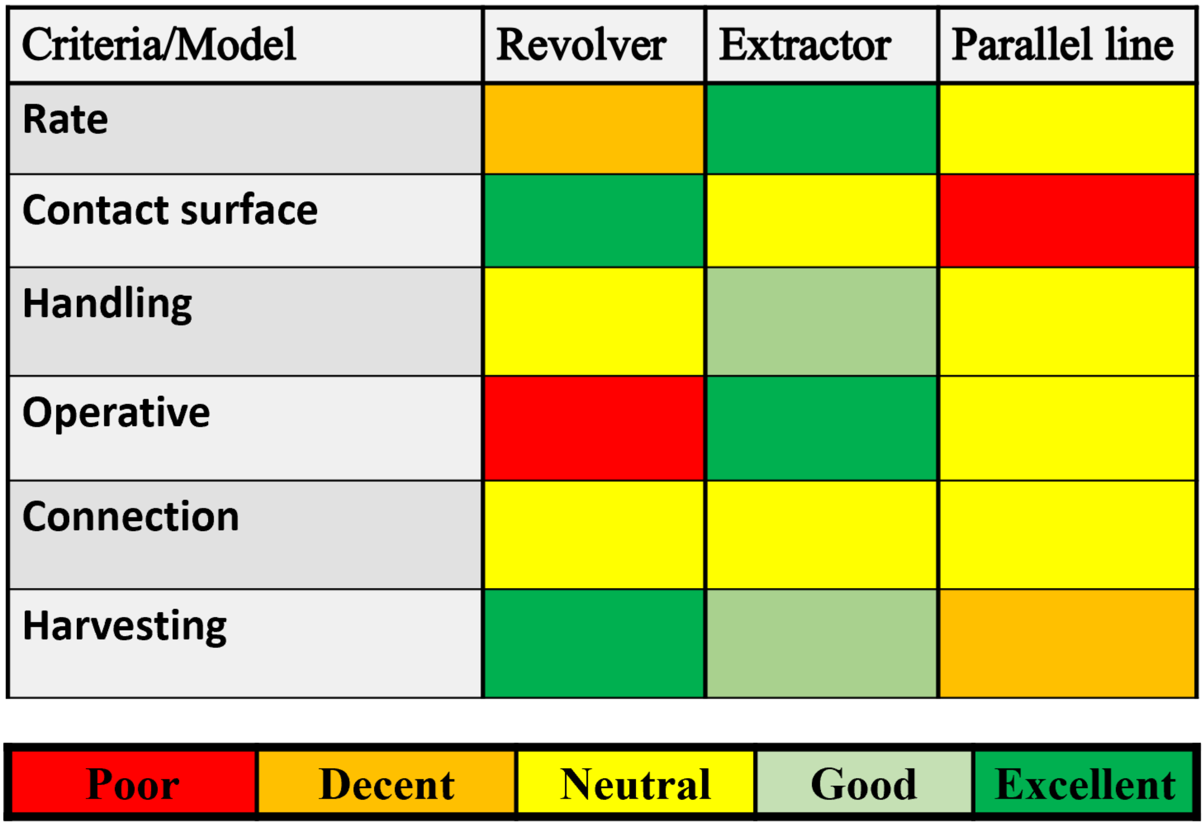


Figure 23: Evaluation matrix of the concepts

7.3 Concept selection

Parallel line
The concerns related to the connecting mechanism forms the basis to discard the concept.

Revolver
The Revolver method satisfies many of the set requirements. The complex mechanism along with a low combining rate makes the concepts not suited for further development. The concepts are therefore discarded.

Extractor
The Extractor satisfies most of the requirements. There are some aspects that need to be investigated further, to ensure it meets all of the requirements. The main benefit is the great potential for up-scaling while it keeps its simplicity.

Conclusion: The extractor will be the combining method used for further development.

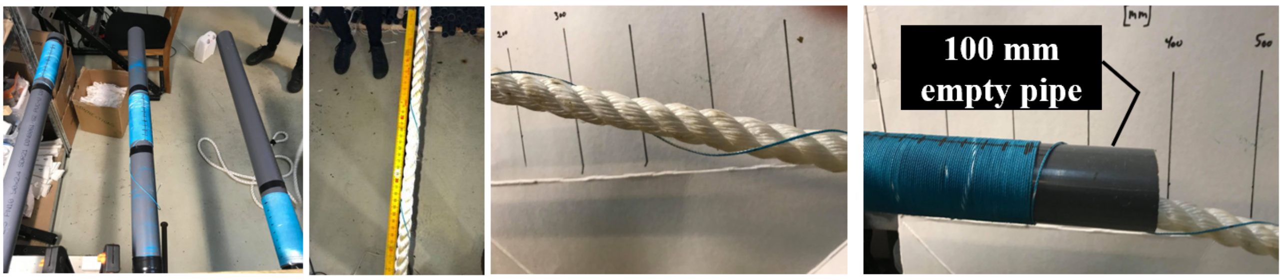
7.4 Testing of the chosen concept

After evaluation and comparison, the extraction is found most promising for further development. To be able to confirm the chosen concept has the potential required for further development, more detailed tests have been carried out.

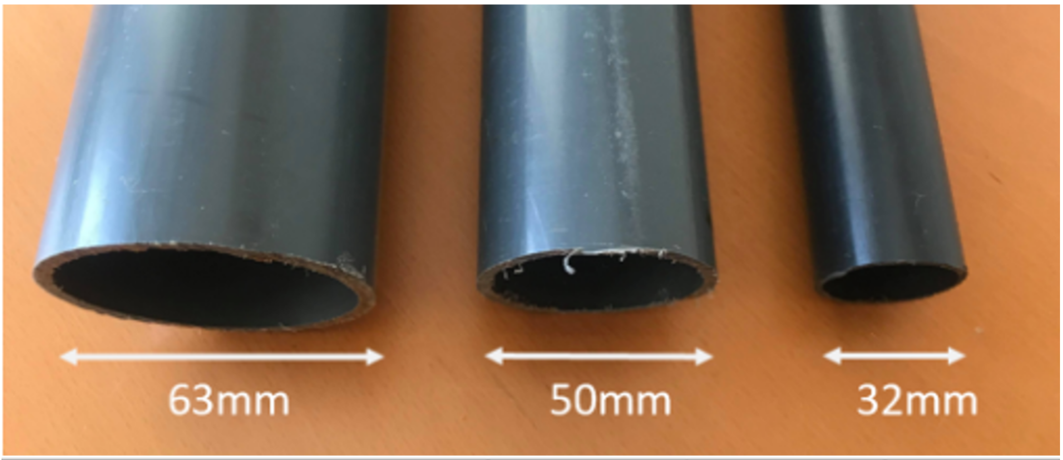
It is important to emphasize that the main function is a known concept. So why is this method chosen as a concept for further development? The extraction is considered a method with potential, especially for streamlining. The method has been used as an easy technique for new farmers to combine kelp lines. However, it is not found many attempts on streamlining the method yet.

Before moving to the next stage, some of the most important discoveries from the testing will be presented, especially related to the requirements that were not fully met in the Evaluation and comparison chapter (7.2. The seeding spool size is desired to be 700mm long, and a diameter of 50mm. It is ideal that the extractor can produce 50 meters of kelp line with one seeding spool, related to the demand of floating elements after 50 meters.

Contact surface
One of the concerns regarding the Extractor was poor contact surface between the seeding line and the carrying rope. A test was completed to investigate this concern. It was proven the first 100mm of the seeding line, easily fall over to the carrying rope, without tensile force, resulting in poor contact surface. It was concluded to avoid coiling seeding line onto the first 100mm of the PVC pipe. This makes the concern related to contact surface negligible. For further information regarding the test, see chapter 19.4.



Periods
Another concern regarding the extractor was period manipulation. A test related to what period the concept could provide was executed. It showed that the Ø50mm pipe will provide 150mm periods, but by increasing or decreasing the diameter of the pipe, the periods can be manipulated. Three standard sizes of PVC pipes were tested.



Period / Spool width	63mm	50mm	32mm
Average period length	20.4 cm	14.9 cm	9.2 cm

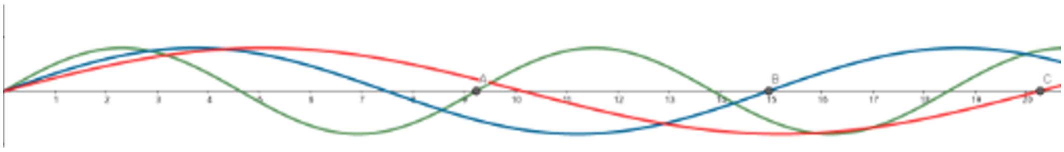


Figure 24: A representation of periods with different diameters

If periods beneath 90mm are desired, using two seeding spools in series and combining them to one carrying a rope, will fulfill the demand. For instance, 75mm periods can be achieved with two 50mm seeding spools in series. See Figure 25. All the variations related to this test should cover the demand for different periods. The Ø50mm pipe, which gives 150mm periods will be used for further development. For further information regarding period testing, see chapter 19.6.

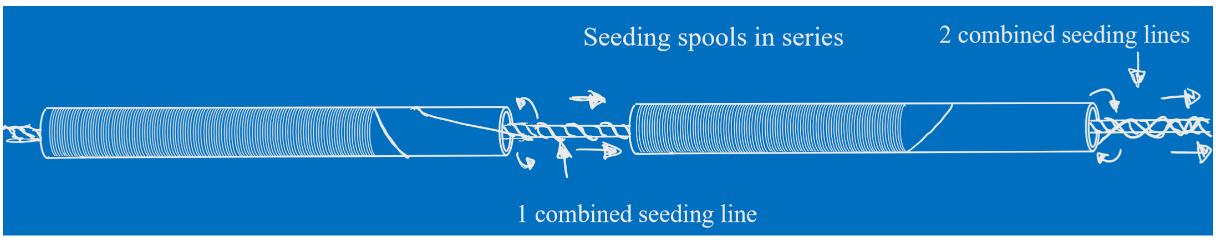
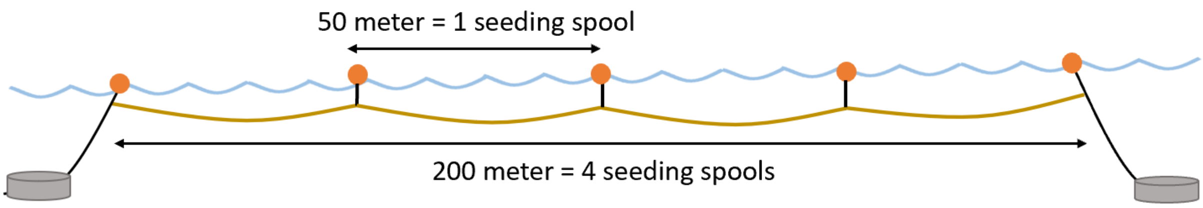


Figure 25: Illustration of how two seeding spools can be combined at once

Lengths
To minimize waste of seeding line, each spool should produce a set number of meters of kelp line. The extractor with Ø50 mm pipe showed that the 700 mm coiled seeding line gave 71 meters of kelp line. In other words, a 700 mm seeding spool gives an approximately 70-meter kelp line.

A floating element is attached every 50 meters, and kelp lines of 50 meters are desirable. It can be achieved with one seeding spool. This will be provided with a 500mm coiled seeding line. It will be 100mm of empty pipe at each end of the spool. This could provide space for mounting, handling of the spools without touching the seeding line, and the demand of not coiling onto the first 100mm.



7.5 Evaluation prior to next stage

The extractor has been tested to discover flaws related to the requirements. The tests have been important to investigate the properties, and by evaluating the result from the testing, the extractor will be used. Figure 26 shows the combining.

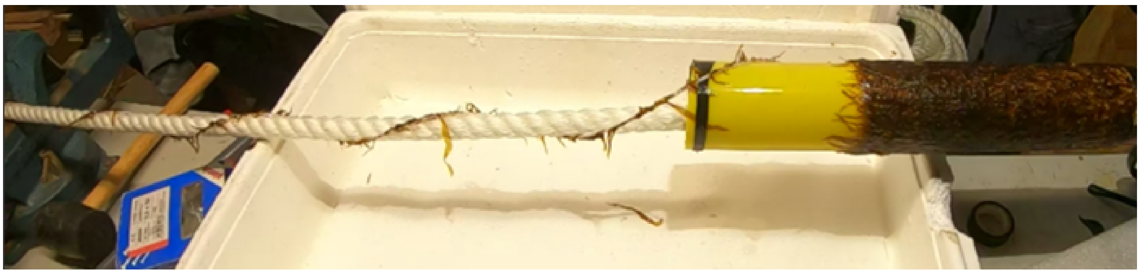


Figure 26: Extractor combining seeding line and carrying rope

8 Operating conditions

The combination method is determined, and stage 1 is completed. The operating conditions of the machine must be defined next. Initially, the machine was supposed to be placed on a boat, where the combining and deployment would happen at the same time. From experiences and observations, an idea was introduced; producing the kelp lines at land, to simplify the process at sea. This was considered a game-changer in the development process. An overview is illustrated in Figure 27.

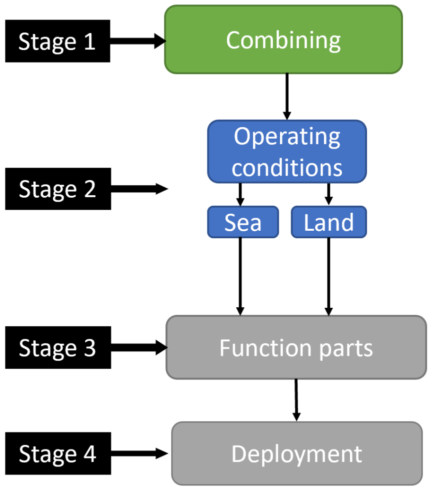


Figure 27: Overview of the development process

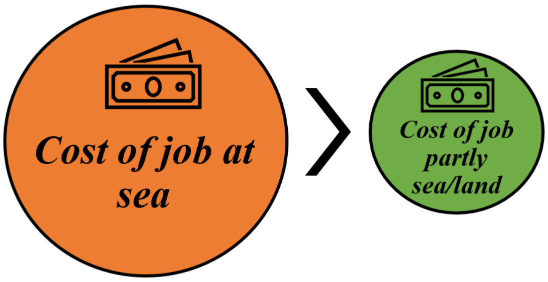
8.1 Basis for the idea

The group joined Seaweed Solutions to Frøya for the deployment of kelp lines. Two methods of deploying were tested - combining and deployment directly from the boat, and deployment of pre-produced kelp lines. The experiences were important to form the idea of moving the combining to land. During the combining and deployment at sea, knotting and preparation of ropes was a time-consuming part. This could be done in advance at land. Work at sea is delicate and exposed, and it is desired to complete as much of the work at land before heading out.

The idea of preparing as much as possible on land, to ensure efficiency and minimize potential delays at sea, is a work strategy at sea. By dividing combination and deployment into two separate processes, the idea is to achieve this. To get an insight into the benefits and challenges by dividing the process, different aspects will be presented in the following subsections.

8.2 Benefits and challenges of land-based combining

Deployment is an exposed and sensitive part of the cultivation, and the available work hours at sea are restricted. This leads to the demand for high efficiency at sea. Moving the combining to land, makes it possible to bring deployable kelp lines to the farm. This reduces the equipment at sea and can provide faster deployment rates since it is not depending on the machine to combine while deploying.



Kelp spores are fragile and have strict demands related to their environment. This makes dividing of combining and deployment challenging since the main reason for having a combining machine working from a boat was to assure that the kelp would be exposed to a minimum amount of handling and contamination before deployment.

By dividing, there must be taken precautions to avoid unwanted damage to the kelp spores. It would be advantageous that the combining happens near the deployment site, to reduce the time spent in a non-ideal environment. Most of the challenges regarding dividing the two stages are related to biological aspects. The opportunities to discover all parts of the challenge reduces, but through advice from SES, the group can reach a decision.

To summarize how the process is visioned, the combining happens on land in a facility ensuring the right conditions for the kelp. The kelp lines will be stored in a container, which will minimize the handling of the kelp line. The kelp lines are transported to sea and deployed with high efficiency from the container it was stored in. The only equipment required is the kelp lines and floating elements. The need for manual labor is connecting the kelp lines to the floating elements and to the framework of the farm.

8.3 Evaluation and conclusion

To evaluate the two different scenarios, it is essential to compare them to the requirements. An evaluation matrix based on them is illustrated in Figure 28. Not all of the requirements are possible to compare with sea or land-based combining. The ones marked in yellow are neutral. The other requirements are determined on the basis of the experiences and observations the group has made from fieldwork and testing.

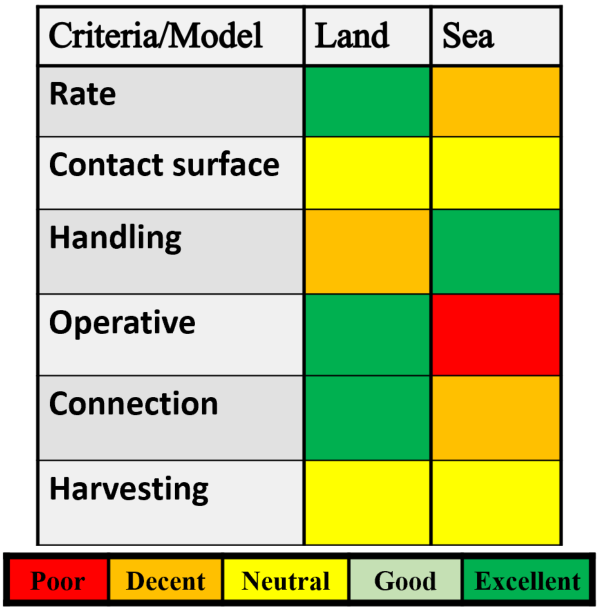


Figure 28: Evaluation matrix of sea vs. land

- **Rate** - The combining speed is estimated to be about the same, but the rate of deploying kelp lines has shown to be much higher, with land-based.
- **Contact Surface** - There are no indications that either stands out.
- **Handling** - Sea-based combining is considered a method for low handling, while there still is little research related to land-based production.
- **Operative** - The operating conditions are considered much simpler and safer when reducing the number of tasks and equipment in use at sea.
- **Connection** - Preparing and completing many of the tasks at land, can reduce the connections necessary at sea.
- **Harvesting** - There are no clear indications that either stands out.

From the evaluation matrix, it is estimated that handling is the only requirement that is worse on land versus sea.

The survival of the kelp spores must be investigated further. If the desired conditions are not satisfied, the kelp spores will not survive. It is therefore essential to facilitate minimum handling of the kelp. Two tests were executed to investigate the survival of kelp spores.

1. In field test - chapter 19.1

Kelp line was produced on the dock, transported to the farm and deployed from buckets. It is to early to constant the growth of the kelp, but it was proven the savings regarding time at sea.

Figure 29: Deployment of kelp lines combined at the dock

2. Survival Test Drum - chapter 19.5

Kelp line was produced in the workshop at SES. It was coiled onto a drum and stored in the desired conditions for about 24 hours. The drum was then uncoiled and sections of the rope were put in water pools to see if the kelp had survived. The indications of the kelp spores survival are good. See picture of the kelp spores in Figure 30.

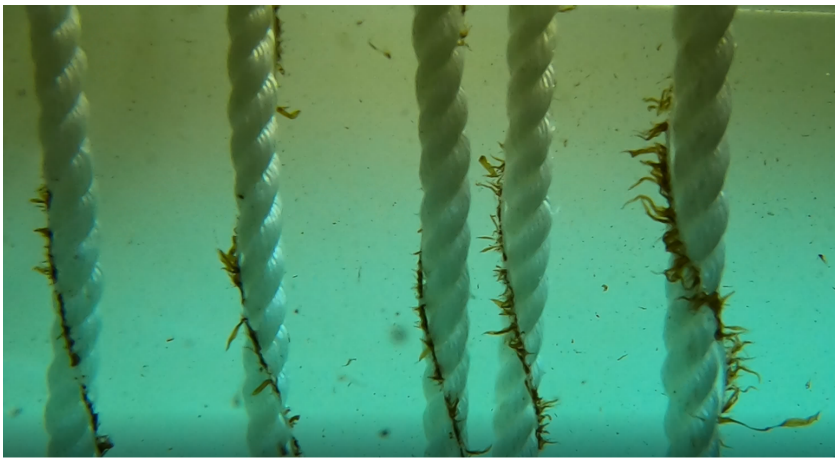


Figure 30: 2 weeks after drum storage

Conclusion
After testing the survival of kelp spores and counseling with SES, it was concluded that the risk is manageable in relation to the gain in efficiency. The extraction method will be developed to produce kelp line on land, and not directly after the boat. The visioned process after **2 stages** of development will then look something like this.

1. Seeding line is being combined with carrying rope from the seeding spool by using the extractor.
2. It produces 50 meters of kelp lines, which is stored in a storage unit maintaining the ideal conditions
3. The kelp lines are transported to a deployment boat.
4. The kelp lines are placed directly in the farm using a specially developed method.
5. The kelp spores grow in the farm until harvesting

9 Function parts

Stage 1 and 2 are determined. The next stage is to define the function parts, and have a full-fledged combining concept. The process of all the function parts will be the production of kelp lines.

9.1 Overview of the functions

To understand the desired functions in the production, one production cycle will be explained. Each point represents a function. The product of the functions put together is kelp lines. An illustration of the function parts can be seen in Figure 31.

- 01 Carrying rope is prepared and placed in a way to make it ready for production.
- 02 A seeding spool is prepared and applied to the construction.
- 03 The seeding spool is held rigid on the construction by a spool sleeve.
- 04 To ensure movement in the production a drivetrain is used to apply traction to the carrying rope.
- 05 After the carrying rope is pulled through it must be stored in a storage unit.
- 06 The previous functions are held rigid by a constructional framework.

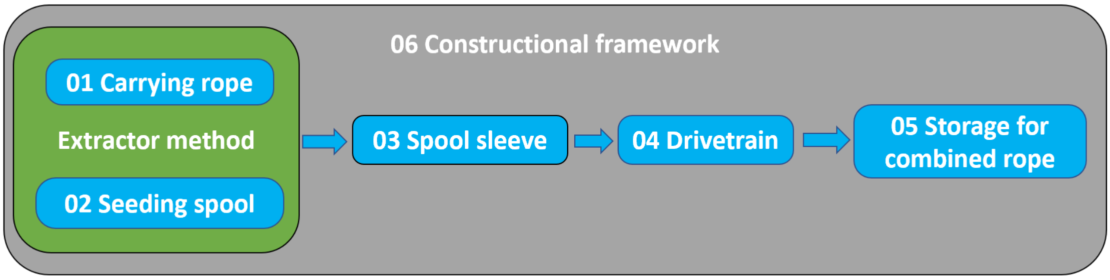


Figure 31: The different functions and components of the production

In the next subsections, each function will be described and presented with a list of functional requirements. Some of the requirements are linked to the final requirements (5), while others are specific to its function. Functions presented with different variations are crucial for further development will be evaluated according to the requirements.

01 Carrying rope

The carrying rope goes into a production like an assembly line in the production. Before production the carrying rope should be soaked in saltwater, to ensure the right environment for the kelp spores. They will be cut in lengths of 50 meters.

Requirements:

1. The rope should be coiled in a pattern that prevents knots and unwanted resistance to avoid a reduced rate.
2. The desired lengths of the rope should be cut or marked prior to production, this is to fit the lengths between the floating elements.
3. The rope must be moist with saltwater, this is a preventative measure to minimize handling on the kelp spores.

Coiled ropes on drums are used for handling, storing, and transportation. The drum is not seen as an essential function for the development of the machine, but for the sake of simplicity, the carrying rope is prepared on drums in advance.

Figure 32: Carrying rope coiled on a drum

02 Seeding spool

The seeding spool can have different lengths and diameters. The variations related to this are presented in stage 1 and in the period testing (chapter 19.6). The size of Ø50mm and length of 700mm were determined. The carrying rope is a 3-ended rope, which makes up a characteristic pattern. The direction of the seeding line can be determined by the direction of the seeding spool. Testing has shown that the direction of rotation may inflict the combined result.

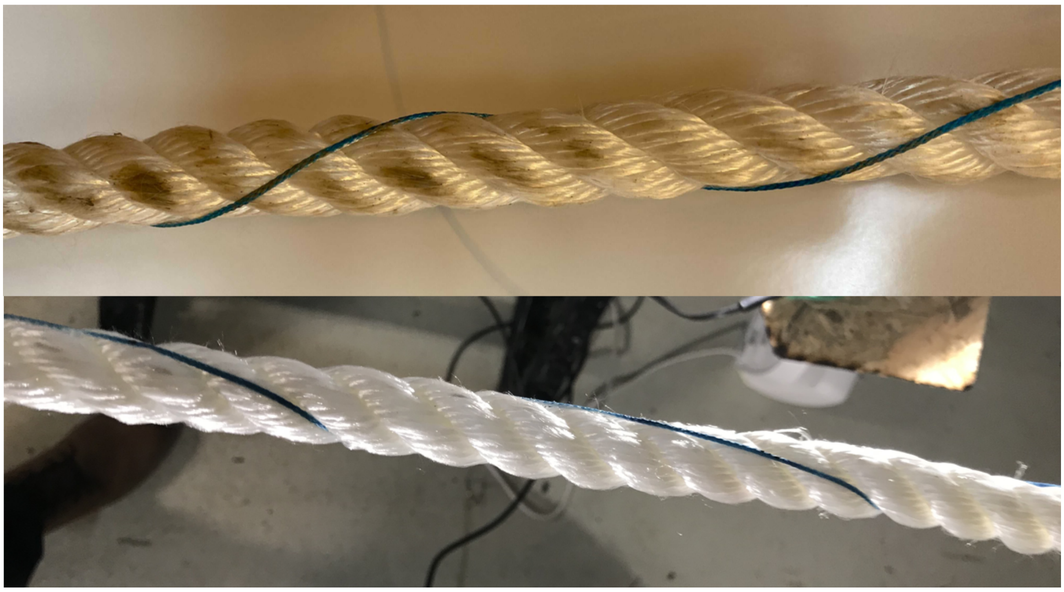


Figure 33: Upper picture shows counter wise combining, picture below shows combining in the same direction as the rope.

From testing, combining counter-wise (top picture), the period and contact surface were more stable. When combining in the opposite direction, the seeding line tends to get stuck in the grooves of the carrying rope. This may lead to unwanted handling of the seeding line.

03 Spool sleeve

The purpose of the spool sleeve is to hold the seeding spool fastened, without interacting with the combination. The sleeve will determine which angle and direction the combination will be executed in. Related to this, a test was executed to explore the benefits regarding the direction of the production (Combination Variations test, chapter 19.2. Numerous ways to perform the combination process were tested. The conclusion from the test was that there were seen no benefits from changing the direction of combining. Therefore a horizontal direction is considered the most sensible, making the construction more operative for workers. The spool sleeve has to lock the seeding spool to keep it in place. The sleeve spool must be compatible with a standard seeding spool.

Requirements:

1. The sleeve will be a rigid construction that holds the seeding spool while it is being emptied.
2. The sleeve must have a locking mechanism, keeping the seeding spool in place, which should be relatively easy to fix and open repeatedly.
3. It should not interfere with the combination process.

Concepts:

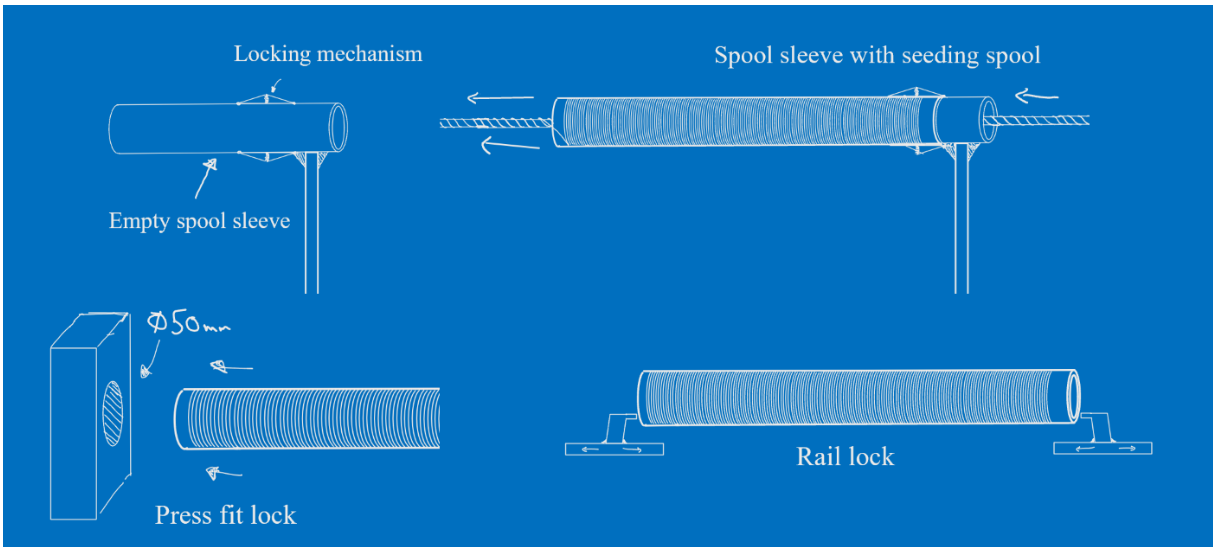


Figure 34: Draft of the spool sleeve concepts

All concepts related to the same function and should meet the set requirements. The function will not be further detailed since it not necessary for the final concept design.

04 Drivetrain

The function of the drivetrain is to create traction in the carrying rope. Since the production is moved to land, there will be no help from the movement of the boat. A drivetrain is required to do the combination. The drivetrain is divided into two parts; the mechanism creating traction and the power source.

Requirements:

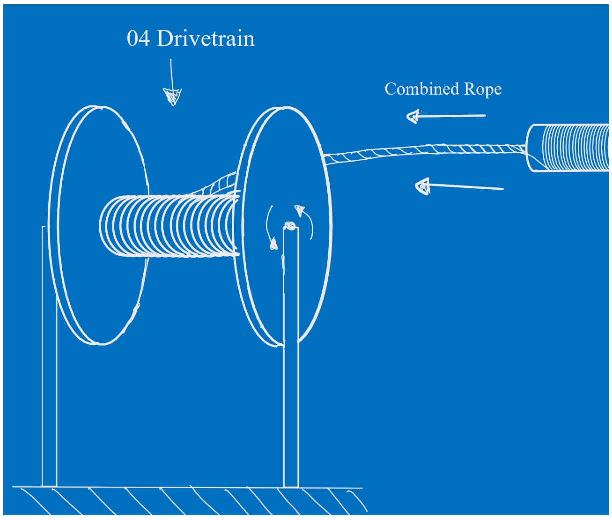
1. The drivetrain should inflict minimal handling on the kelp spores.
2. The drivetrain should create continuous traction, to maintain stable production and avoid uneven combining results.

Drivetrain mechanism

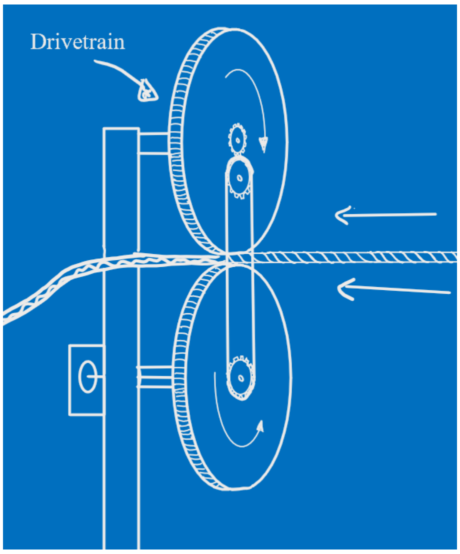
From concept generation, there are two systems presented. It is arguably other solutions, but these two fundamentally different methods are found the most sensible to present.

(a) Winch system. Attaching the rope to a rotating axis will drag the kelp line on a drum.

(b) Pasta roller. Wheels rotating against each other, while the rope is inserted between the wheels. The rotating wheels will be squeezed against each other creating traction to the kelp line.



(a) The kelp line collected on a drum, looking like a big winch.



(b) Two wheels rotating against each other creating traction to the kelp line.

Power source

The drivetrain needs a force, which will be applied to the mechanism creating traction of the kelp lines. During testing, the power sources have mostly been pulling by hand. This shows that the production does not need large forces to function. Three sources of pulling forces have been considered and are presented in Figure 36.

1. Manual labor, an operator could provide force to the drivetrain. This is not an ideal solution for a task that will be repeated many times, it will also limit further upscaling.

2. Fuel engine, a fossil engine can be installed to provide a lot of power. It is considered an exaggeration.

3. Electric motor will provide force from electricity. It delivers stable traction, even with a lot of starts and stops. The needed force is easy to deliver.

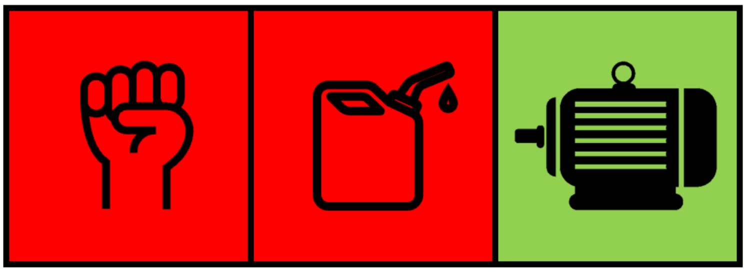


Figure 36: Power sources; Manual, fuel engine and electric motor

An electric motor is concluded as a suitable option. For the sake of simplicity, this conclusion will not be further developed. The necessary specifications related to performance and regulatory possibilities, will not be further detailed.

05 Storage for kelp lines

The kelp lines need to be stored, and get ready for transportation to the farm. The biological aspects are important. The kelp lines must be placed in a climate suitable for the kelp spores.

Requirements:

1. Storage should maintain the desired conditions for the kelp spores.
2. The kelp lines should be stored in a pattern that facilitates effective deployment.

The storage unit is inspired by the outcome of **04 Drivetrain**, and the two functions with the drivetrain are presented. A draft can be seen in Figure 37.

Drum storage: If the drivetrain consists of a winch system a changeable drum could be used as the winch. When the winch has coiled the kelp lines on the drum, it could be detached. The drum would then work as a storage unit.

Pool system: The kelp lines can be feed into a pool or bucket. The pool could be filled with saltwater. The pool would maintain spacing between the kelp lines, reducing the pressure.

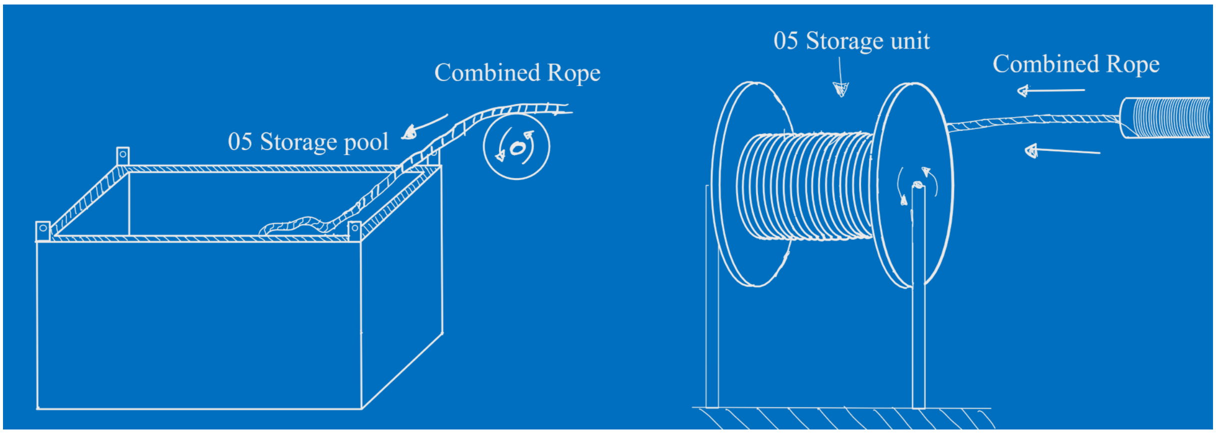


Figure 37: Pool storage (left) and Drum storage (right)

Further evaluation of the two concepts will be done later in this section.

06 Constructional framework

The functions 01-05 need a framework to keep the parts fixed, it will ensure the right placement and lengths between all the functions. The previously mentioned functions need to be chosen to provide any concepts related to the constructional framework.
Requirements:

1. Keep all parts fixed in the desired positions.
2. Ensure operative working conditions.
3. Facilitate all the requirements for the mentioned function parts are satisfied.

Evaluation of undetermined parts

All function parts are now described in relation to their function, requirements, and different variations. To facilitate further development, it is essential to determine all the parts. The functions of the drivetrain and storage unit are considered the most important features for further concept evaluation and need to be evaluated. The drivetrain and storage unit is closely related, so they will be evaluated together.

The two concepts have advantages and disadvantages, which mostly is related to the biological aspect in this case. In order to make a decision tests have been performed. For evaluation, it will be presented the relevant tests with positive and negative properties, and in the end an evaluation matrix with the requirements.

Winch and drum storage

Figure 38: Kelp lines coiled on drums

The winch and drum storage has its advantages in terms of combining, storage, and deployment rate. The biggest concern regarding the winch and drum storage is the handling. Coiling on drums has a moment of uncertainty to the requirement regarding handling. To be able to argue against this concern, a survival test was completed. The test was concluded as passed (Survival Test Drum, chapter 19.5). When the rope is coiled on drums, the kelp spores are subjected to a compressive force, which is better than friction. The drums have not been tested for deployment in the sea, but it is considered to be feasible.

Positive

- Simplification of the production
- Facilitate for efficient deployment
- Maintains the contact surface because the tension is maintained when coiled

Negative

- Coiling can result in critical damage to the kelp spores
- The shaft of the winch needs to be removable

Pasta Roller with storage pool

Figure 39: Kelp lines in storage pool

The pool system is supplied with the pasta roller because it only provides traction. The conditions for the kelp spores are good in a saltwater pool. It is during transport, the handling criteria are being challenged. The kelp lines will be rubbing against each other, and friction is bad for the kelp spores. When it is put into a pool, the tension in the kelp lines disappears, which results in less contact surface between the seeding line and the carrying rope.

Positive

- Easy to maintain good conditions for the kelp spores, by having salt water in the pool

Negative

- Do not facilitate for efficient deployment by being stored in pools
- Difficult to satisfy tension in the kelp line when stored, which results in bad contact surface
- Transportation of the pools resulting in friction between the kelp lines

Comparison and selection

The requirements are used to evaluate the two concepts.

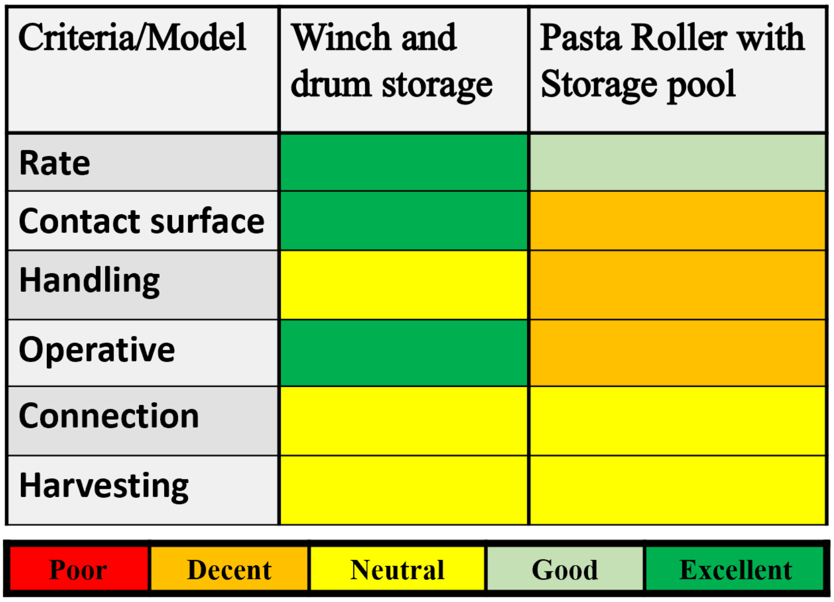


Figure 40: Evaluation matrix based on the requirements

- **Rate** - The combining rate is estimated to be about the same, but the potential deploying rate is considered higher with drums.
- **Contact Surface** - From testing it was discovered loose seeding lines when the kelp lines were stored in pools
- **Handling** - There are concerns regarding the survival of the kelp spores when storing kelp line on drums. Friction between the ropes in the pool is not ideal.
- **Operative** - Drums are easier to operate than pools filled with saltwater.
- **Connection** - There are no clear indications that either stands out.
- **Harvesting** - There are no clear indications that either stands out.

After experience and results from testing it was possible to decide on a concept. Since the Survival Test Drum was passed, the concern regarding handling of kelp spores will be considered negligible for now, but it needs further testing. The drums are considered with great potential for further streamlining, by using them as drivetrain, storage- and deployment unit.

9.2 Defining all functional parts

All the function parts of the production are described and illustrated. The functions can be put together into one concept, which can be seen in Figure 41.

01 Carrying Rope is cut in the desired length, 50 meters, coiled on a drum, and soaked in saltwater before combining. The drum with the carrying rope is placed on a rig where it can rotate around its own axis.

02 Seeding Spool is retrieved from the lab shortly before combining. The seeding spool is put in the desired direction.

03 Spool sleeve The seeding spool is mounted on a spool sleeve. The carrying rope is pulled through and mounted to a drum on the other side of the production line. The seeding line is tied to the carrying rope when it is pulled through.

04 Drivetrain consist of a drum having the kelp line connected to it. As the drivetrain starts to move, the drum will rotate and coiling the kelp lines.

05 Storage unit When the last part of the carrying rope is pulled through the spool sleeve, the seeding line will be tied to the carrying rope. All the kelp line is coiled on the drum. It is detached from the production and stored in the right conditions until deployment.

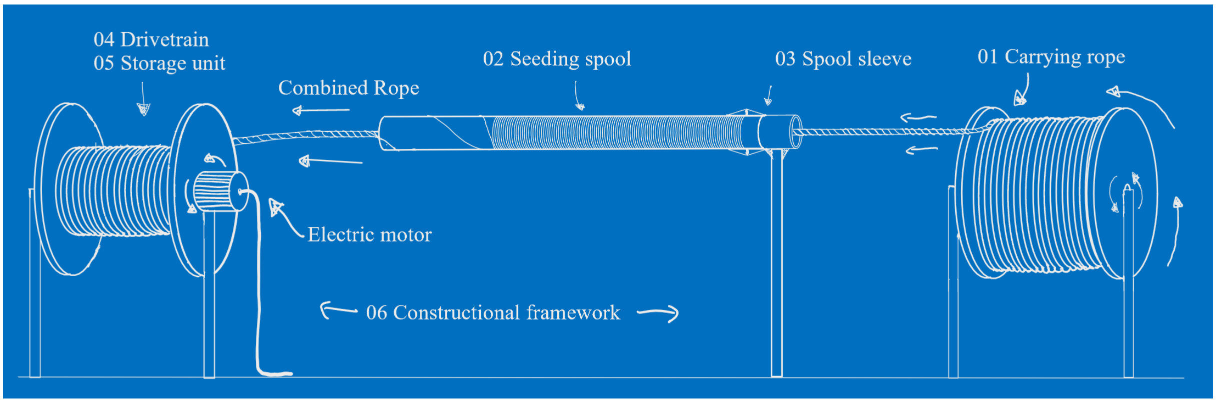


Figure 41: Draft of all the functions put together

10 Deployment

Stage 4 is the last step of the development process. The kelp lines are produced, coiled on drums, and ready for deployment into the farm. Through conversations and discussions with SES, there are three requirements regarding deployment:

1. It is necessary to have a floating element after 50m of kelp line deployed
2. The framework area consists of 200m lengths
3. The deployed rope should be placed with no less than 3-meter spacing.

With the floating element spacing of 50 meters, it was natural to make the same lengths of kelp line. This distance is beneficial, regarding the length of kelp line on a drum. A drum with 50-meter kelp line is movable by an operator. When the deployment boat is loaded with the drums and floating elements, the intended deployment process can start:

A drum will be fixed in a rack. The start of the kelp line is connected to the framework in the sea, and the 50-meter length is deployed by moving the boat. When the drum is empty, the rope is spliced with the rope from the next drum. In addition, the floating element is connected. When four drums are emptied, a 200m length is covered. Then the end of the kelp line is tied to the framework, and one length is finished. The process is illustrated in Figure 42.

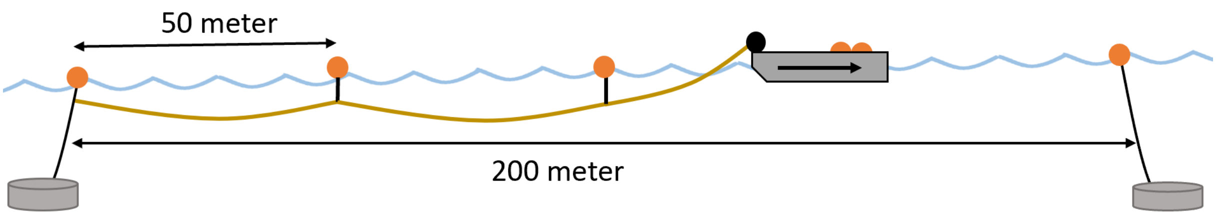


Figure 42: Illustration of deployment

Three functions need to be defined to ensure the deployment:

1. A rack for uncoiling the drum into the sea.
2. Floating elements to keep the rope from sinking.
3. A way of connecting kelp lines to floating elements and framework.

Note! The following chapter will present sensible proposals for solving the three functions mentioned. There will be no conclusions from the proposals, as further detailing and testing in collaboration with SES is needed.

10.1 Deployment rack

The boat used for deployment must have a rack where the drums will be fixed. The end of the kelp line is connected to the framework, and by backing the boat, the drum will uncoil into the farm. The design of the rack will be determined based upon the following requirements:

1. The drums need some resistance during the deployment to avoid over-rotation.
2. Facilitate for an efficient change of drum.
3. Reduce handling of kelp spores to a minimum during deployment.

To satisfy the requirements, a concept of the rack is sketched. The draft for how it could be done can be seen in Figure 43. It was considered two variations of the rack - one horizontally and one vertically. It was no benefits of having the rack vertically. To create resistance to the drum, there will be a connection between the shaft of the rack and the drum.

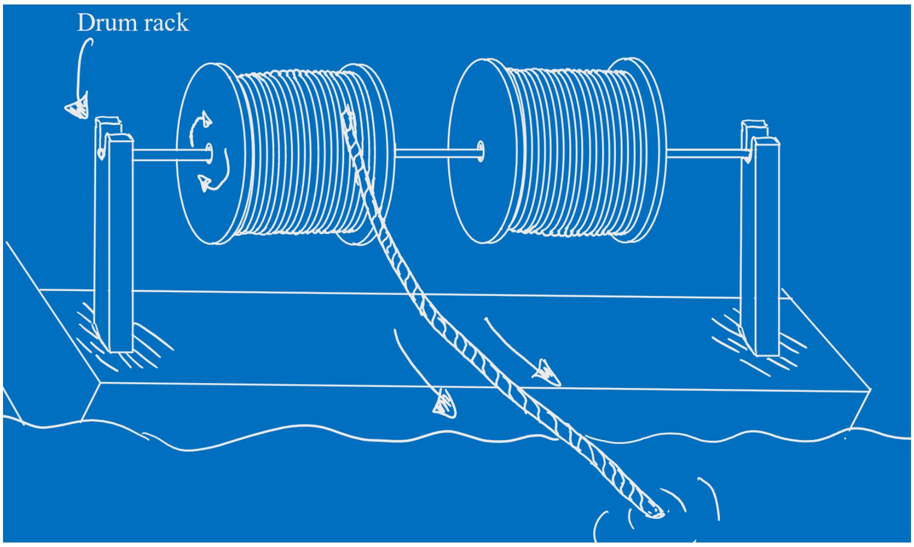


Figure 43: Horizontal deployment rack

10.2 Floating element

The kelp lines must have a floating element at least every 50m. They work as support to decrease tension on the kelp line over the 200-meter lengths and it helps to keep the kelp at the desired depths. It depends on the climate how deep the kelp should be placed for optimal growing conditions. In the farm at Frøya, the desired depth for the kelp line is between 1-3m. The floating element is therefore connected to 1 meter long ropes. It will be natural to place floating elements at the splicing between the kelp lines. The result is the deployment of three floating elements for every 200-meter length. SES use buoys as floating elements and can be seen in Figure 44.

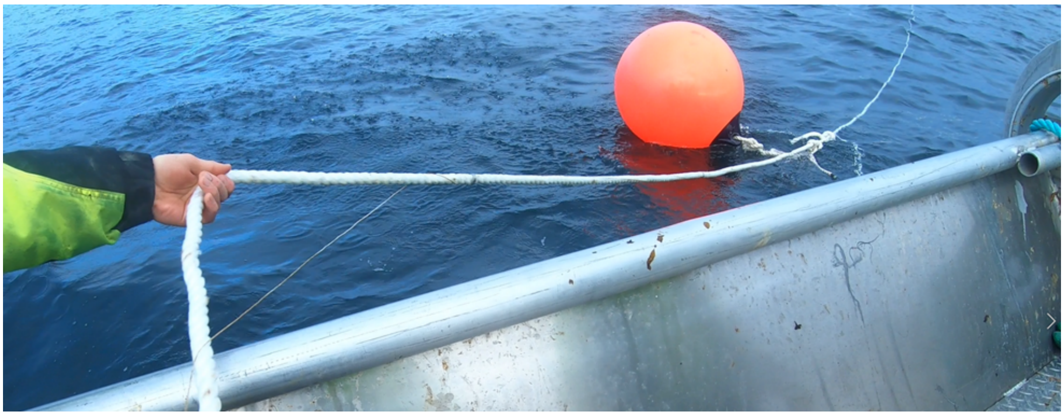


Figure 44: Buoy deployed from the boat

10.3 Connections

Since the kelp lines are deployed in 50m lengths and the framework at sea is 200 meters long, connections are a major part of the deployment process. From experiences from the In Field testing (chapter 19.1), all connections were completed by tying knots by hand at sea, this was a time-consuming process. A brief summary of the connections done in one 200m line of deployment:

- Connecting to the framework in each end (2 times).
- Splicing the 50 meters kelp line to each other (3 times).
- Connection to floating elements (3 times).

The connection of floating elements could be merged into one connection process since the splicing of two ropes will happen at the same time. For most of the testing, carabine hooks been used to represent a connection mechanism. To define what is desired, a list of the requirements is presented:

- The connections should facilitate for fast deployment rate [01]

- Connections should make the operating conditions simpler and safer [04].
- The time used for connections should be reduced compared to the method used today [05].
- The connection should be easy to detach, facilitating efficient harvesting [06].

The number behind each point represents the requirement set prior to the project. The connection is divided into two separate processes. 1. Preparations of the ropes, which can be done prior to deployment, and 2. the connections used while deploying.

Preparations of ropes

When deploying kelp lines, the end of the rope must be connected to the following kelp line, in order to maintain continuity. It has been investigated how to improve the efficiency of splicing two ropes. To facilitate a fast connection at sea, it is essential to do some preparations in advance. There are several ideas, which have been looked into. Some of them are presented in Figure 45 from a visit to Amatec.[5]

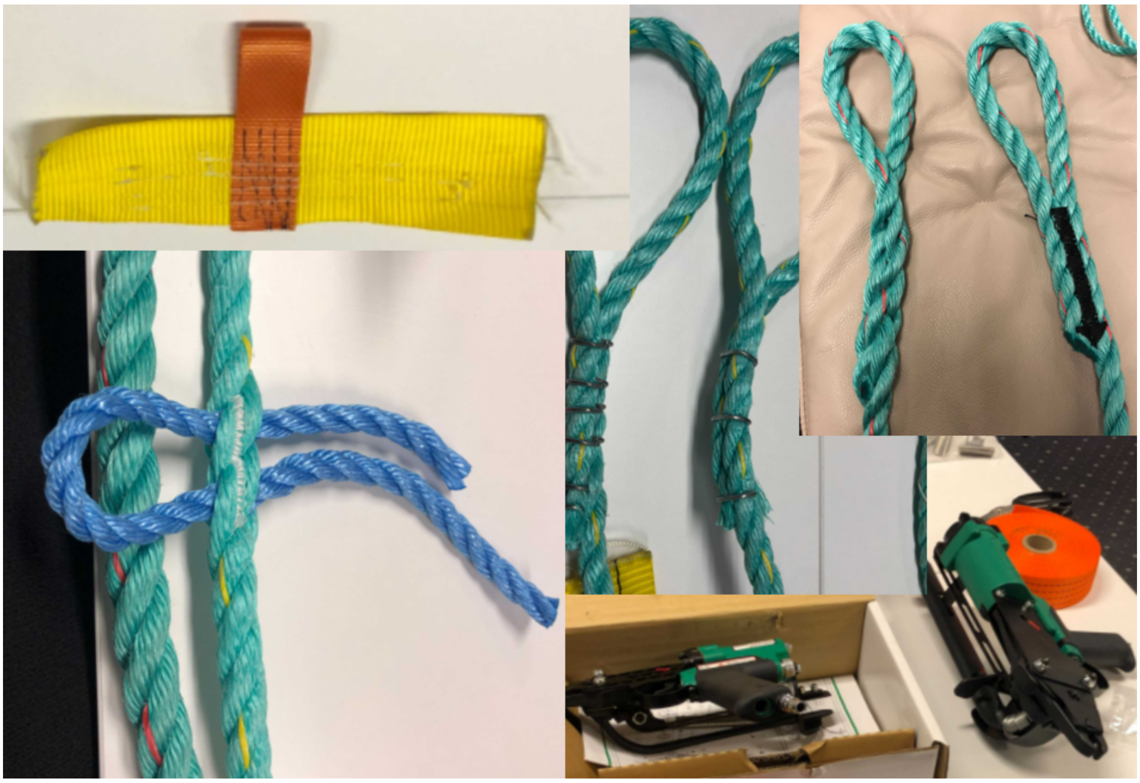


Figure 45: Ideas of methods to prepare ropes

The loops at the end of the kelp lines are a standard method of preparing ropes. These preparations can be done on the carrying rope prior to production. The pieces of ropes connected to the buoys can also be prepared prior to the deployment with similar loops.

Connection mechanism

If the end of the ropes is made with loops, there are mechanisms like carabine hooks, shackles, halibut clips, and plastic strips that can be used. While exploring this field, the group decided it is not essential to decide which mechanism to use, for further development. In the testing, carabine hooks have been used to represent this mechanism. The potential in time savings has on the other hand been further explored to ensure using a connection mechanism is the right way to go.

Figure 46: Splicing by carabine and eye splice (left) and knot (right).

	Knot [sec]	**Carabine [sec]**
Average from 10 measurements	**35**	**5**

Figure 47: Connecting buoy by carabine and eye splice (left) and knot (right).

Connection rope to rope

By preparing the carrying with loops in prior, it is ready to be spliced with a fastening mechanism during deployment. The method has been tested both in the workshop and from a moving vehicle (Asphalt Seaweed Shuttle, chapter 19.7). There is a potential of saving time with this concept.

Figure 48: Splicing of kelp lines using a carabiner hook

Connection rope to buoy

If buoys are prepared with a rope with a loop, in the end, it can be a part of the connection of splicing. A connection mechanism can lock all three loops to each other.

Figure 49: Splicing of two kelp lines and a buoy

Connection to the framework

The framework in the ocean is permanently placed, so the friction on the framework-ropes should be reduced to a minimum. It is been made clear from SES, that it is not desired to use metal for connecting to the framework ropes, since it could tear the ropes off. The only way of connecting is to tie the ropes together manually. When connecting to the framework, the ropes will need to be raised, and an operator needs to tie a knot to splice the kelp line and the framework rope. This is considered a time-consuming task, which should be reduced. It has been considered that further development of these connections must come under further work, due to its complexity.

Evaluation of deployment

From observations and testing, the current way of connecting does not meet the requirements. It is desired to remove all manual labor that is not necessary. Connecting floating elements and ropes by using faster connection mechanisms is an effective measure satisfy the requirements. Through the chapter it has been presented different proposes for how the connections can be performed. However, there will be no conclusion on which method to be considered as most suited.

There is uncertainty related to materials and dimensions, it has therefore not been found appropriate to make a decision. The exact method, is not essential for completing the development process. It needs further work.

11 Concept overview

All the five stages of the development are complete and a full proposal of the process can be presented. A concept of the combining machine has been designed (Figure 50) and a concept idea of the deployment (Figure 51). The visioned process will be as follow:

- After the breeding is finished, the seeding spools are ready for the combining process.
- A drum with carrying rope (01), is placed on the shaft and put into position in the constructional framework (06)
- The seeding spool(02) is put on the spool sleeve(03) and fastened.
- An empty drum(05) is placed at the end of the framework construction.
- The combining process can start. The drum with the carrying rope is extracted through the spool sleeve, and the seeding line is fastened to the end. The kelp line is then connected to the empty drum.
- The drivetrain (04) will start, and the empty drum will work as a winch, and coil the kelp line.
- When the drum with the carrying rope is empty, the drum with kelp line is ready for deployment. The empty seeding spools and the drum is removed, and one cycle is finished.

Figure 50: Combining machine

The finished product from the combining are drums with 50 meters kelp line, ready for transport to the farm. When the drums have been transported to the deployment boat on the farm, the deployment section can start.

- The deployment boat is located by the framework. A drum is put on the deployment rack, and the end of the kelp line is connected to the framework.
- When the kelp line is connected, the movement of the boat can start. While the boat is moving, the drum will rotate and the kelp line will deploy into the sea.
- After 50m, the drum is empty. A floating element needs to be connected, and the next drum with kelp line will be spliced and put on the deployment rack.
- The process is repeated 4 times, and a 200m length is covered.

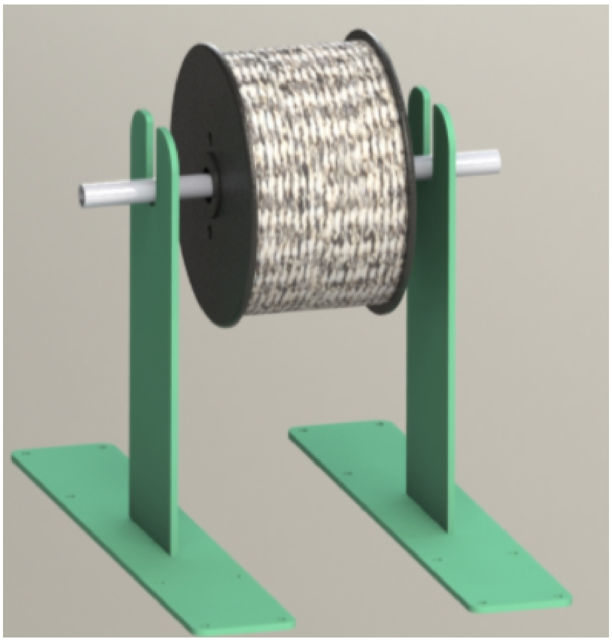


Figure 51: Deployment device

12 Scaling

The main goal for the concepts was to increase the efficiency and facilitate upscaling (Requirements in chapter 5) related to cultivation. In this chapter, the focus is to look further into how the chosen concept can be upscaled. The idea is to duplicate the concept and use it in parallel, series, or both. Tests were performed in the workshop to simulate the combination of three drums at the same time - Multiline Combination, chapter 19.4. Deployment was also simulated by using a car on a parking lot Asphalt Seaweed Shuttle, chapter 19.7. It is important to have min mind, that the tests were only simple models of the concept, and were performed to explore the potential in combining and deploying in parallel. The tests showed potential in increase the efficiency.

Figure 52: Combining test at the workshop using 3 drums

Figure 53: Deployment test using 3 drums from a car.

Designing the concept in parallel and series, will deliver and deploy more kelp line in a shorter period, resulting in more efficient use of time, also referred to as streamlining. The principle of parallel and series can be applied to the combining and deployment concept.

12.1 Combining

Parallel

Figure 54 is a conceptual idea, where the Extractor is designed in parallel. The machine will work in the same order as the concept described in chapter 11, besides working in parallel. The outcome is more kelp line in a shorter amount of time, ready for deployment. The concept variations are presented with four combinations happening simultaneously. This is to simply illustrate the potential, it could also have been 3, 5, or 10 in parallel.

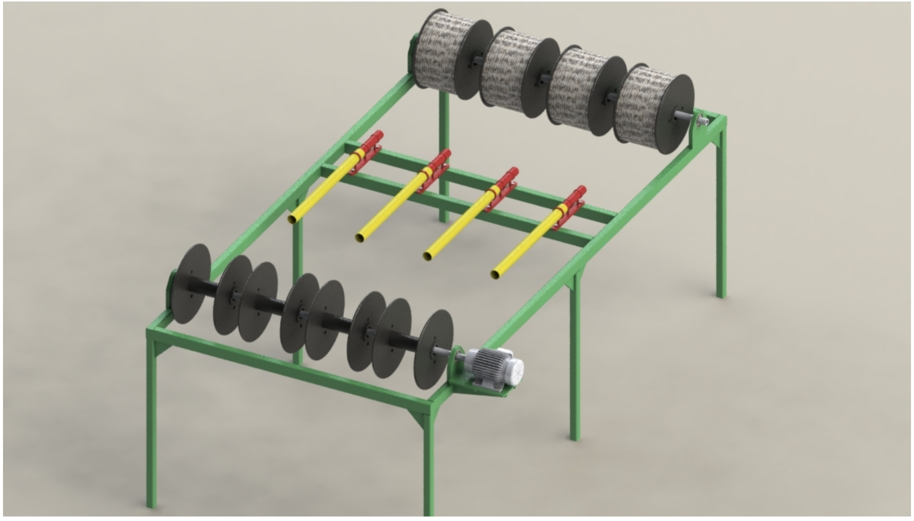


Figure 54: Illustration of combining on several drums

After one production cycle is finished, the four drums consist of 50 meters of kelp line, which is 200 meters in total. The shaft with the drums could be removed, and be prepared for transport to the farm. Then a new shaft with four empty drums on one side and a shaft with four drums with carrying rope on the other side can be mounted, prior to new production.

Series
Figure 55 is another conceptual idea that is sensible to present, where the extractor is designed in series. By setting four seeding spools in a series, the result would be four lengths of 50m kelp line. This will result in one drum with a 200m kelp line. Combining on 200m drums will demand some new methods for deployment, but having full lengths, the splicing could be done at land. The downside will be the weight of the drum and possibly more handling of the kelp spores. It could be possible to reduce the periods by combining in series like shown in test related to periods (Periods, chapter 19.6), by fastening several seeding lines to the carrying rope.

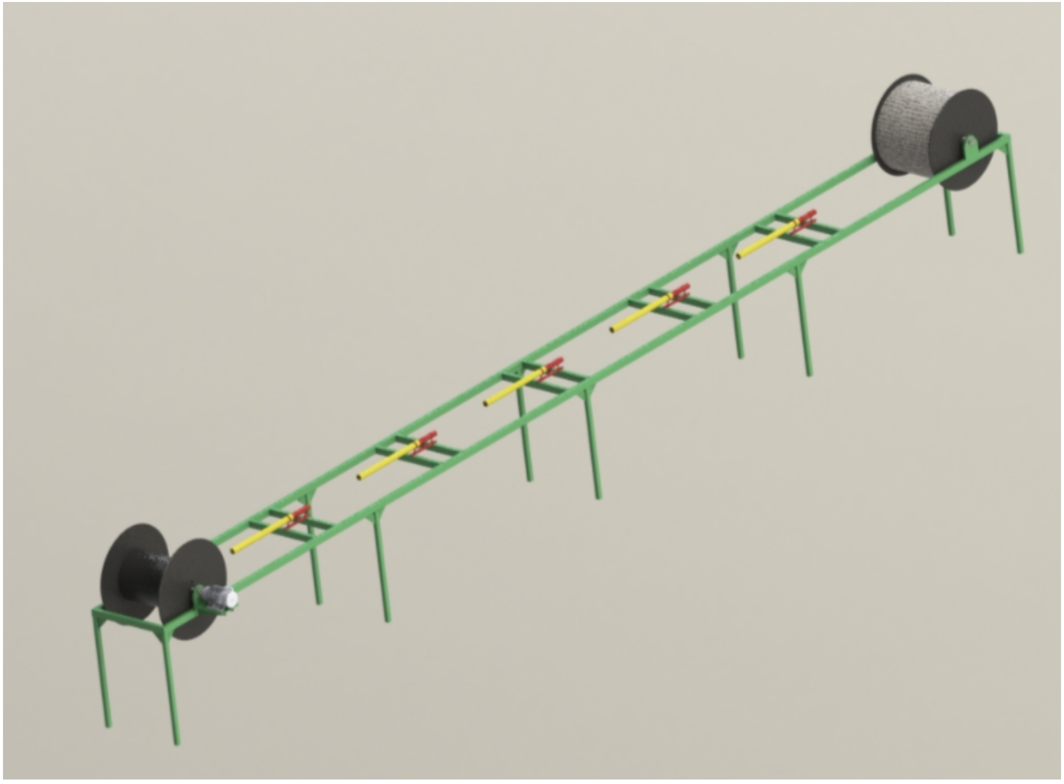


Figure 55: Serial combining

There are many options for scaling. A combination of parallel and series. At this stage, it is necessary to get more experience and results from the harvesting. The concepts are presented to show the potential for further scaling.

12.2 Deployment

Deploying in parallel is considered a with potential for further development. Figure 57 is a conceptual idea, where the drums with kelp line are placed on a horizontal rack. The procedure will be the same as in chapter 11, besides deploying more kelp line at the same time. By deploying in parallel the deployment boat has less stop-time, and the deployment distance is reduced. For this way of deploying it would be a demand for some new techniques.

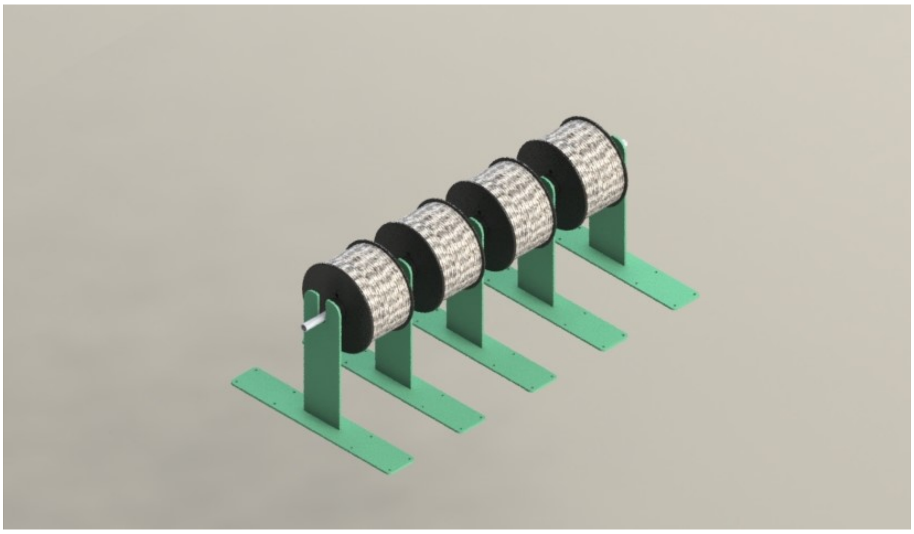


Figure 56: Illustration of deployment rack that could be placed on the deployment boat

An overview shows how the deployment of four kelp lines at the same time could look like. Even if it complicates the deployment it is believed it could be time-saving when at sea. Since the boat could deploy 800 meters of kelp line in one movement. It is difficult to tell how many kelp lines are ideal to deploy at once, but it is largely depending on the size of the boat in use.

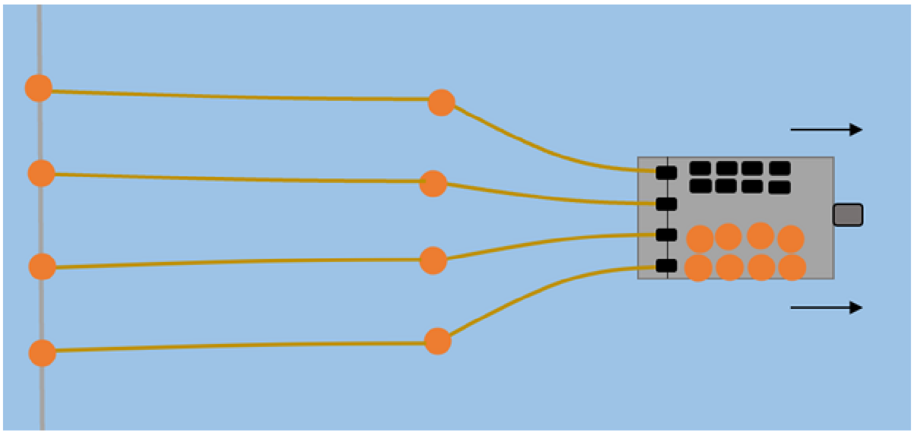


Figure 57: Illustration of 4-line deployment seen from above

12.3 Final concept

It is important to emphasize that the concept is a proposal for a process, and it is not detailed or dimensioned to a great extent.

The concept involves two separate processes, combining and deploying. The combining contains a process where a carrying rope and a seeding line are combined on a land-based facility. The kelp line will be coiled onto drums. The combination can be done on several drums simultaneously, by being connected on the same shaft. This will streamline the work at land. The drums will be transported to a farm where they can be deployed.

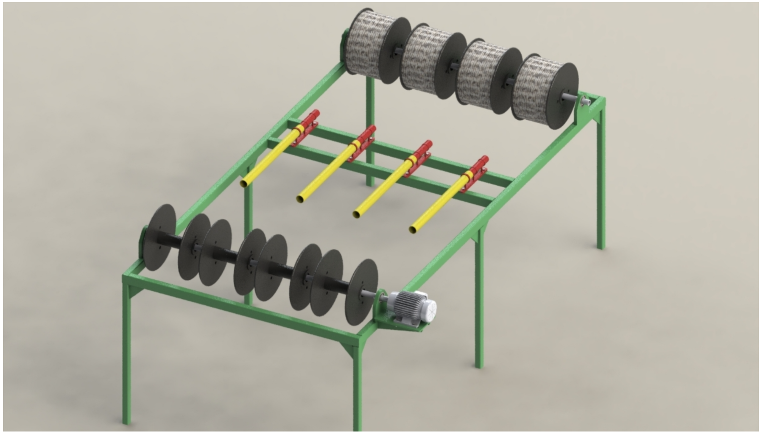


Figure 58: Conceptual illustration of combining construction

The drums from the combining are used for deploying. By placing drums on a rack, the drum will be uncoiled directly to the farm. Deploying several kelp lines at once will increase the length of ropes that can be deployed within a given time. It will also significantly reduce the number of times needed to stop the boat.

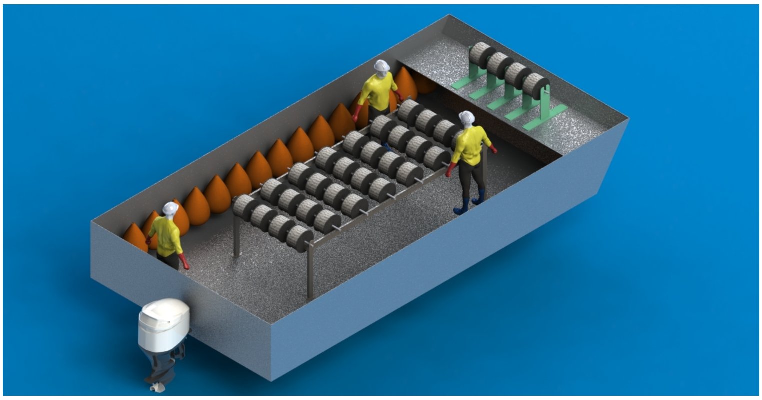


Figure 59: Conceptual illustration of boat during deployment

Through testing and development, a potential for streamlining the deployment process was found. While working time on land is increased, the working time and load at sea are seemingly reduced compared to the method used today.

PART IV

RESULTS, DISCUSSIONS, CONCLUSION AND FURTHER WORK

13 Results

Testing has been a major part of the project. Decisions have been made based on the experience and the results from testing. Therefore, the results of the tests will make up the largest part of this chapter. They are linked to the set requirements (Figure 3).

In field - combining and deployment

The full test is presented in the attachments, chapter 19.1.

Hypothesis

When combining, there is a period that give the best result for kelp growth.

Gain experience from using the different combining techniques - revolver, extractor and parallel.

Summary

- Deploying pre-combined kelp lines was less time and energy demanding than using the extractor at sea
- Deploying from buckets was a heavy and space demanding method.
- Combining parallel seeding line to carrying rope did not give a sufficient contact surface.
- Splicing rope and connecting buoys takes approximately 44 seconds per.
- Direction of spinning the seeding line on the carrying rope.
- It is deployed kelp line, with different periods, making it possible to experience how the period affects the harvesting result.

Conclusion

- Based on the results and discussions with SES, simultaneous combining and deployment is inefficient when splicing, changing seeding spools and connections for buoys. As a result, we will look further into dividing these two operations for further development.

No.	Name	Description and goal	Result
01	**Rate**	*Meter kelp line deployed per hour* **Goal: Combining with a rate of 1 m/s** **Goal: Deployment with a rate of 1 m/s**	By dividing the combining and deployment, it will be possible to have a higher rate Experienced the rate of extractor, parallel and spinning johnny
05	**Connection**	Quick connections between ropes, floating elements, and to framework in the sea that are reusable **Goal: Reduce time used for connecting**	Connection of ropes/splicing : 27 - 43sec Fastening buoys : 7 - 11sec
06	**Harvesting**	Facilitate for low faulty production, increase production volume and a less time-consuming harvest of kelp. **Goal: Facilitate for harvesting**	Different periods in the farm Not able to see result, because the kelp needs to grow until after the thesis is delivered

Table 5: The results linked to the requirements

Combination variations

The full test is presented in the attachments, chapter 19.2.

Hypothesis

Different orientations of the seeding spool will give a variation in combining tension.

Summary

- Friction between seeding line and seeding spool makes combining tension and contact surface sufficient, independent from orientation.
- Friction seems to increase proportional to **L** in **Figure 63**, resulting in a greater resistance as the carry rope gets pulled through.
- Drums as storage and drivetrain

Conclusion

- Based on the results and discussion with Seaweed Solutions, the desired seeding spool size will be 700 mm long and a horizontal combining method to ease working conditions. Drums works as drivetrain, but further testing is needed for the storage part.

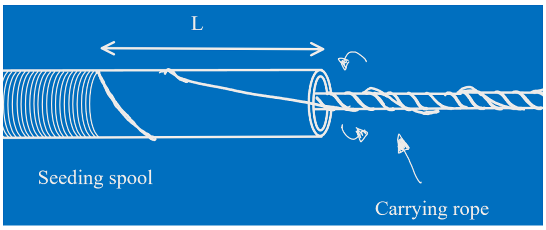


Figure 60:
Combining tension seems to be proportional with the length **L**

No.	Name	Description and goal	Result
02	**Contact surface**	For making it possible for the seaweed to grow on the carrying rope, it is necessary to have a contact surface between the seeding line-and carrying rope. **Goal: The seeding line should have continuous contact with the carrying rope**	The desired seeding spool size is set not to exceed a length of 700mm, due to uneven contact surface
03	**Handling**	It needs to be as little handling of the seeding line as possible. **Goal: Minimum amount of handling of the kelp spores through the process**	Drums as drivetrain works as intented, but needs further testing for how the kelp spores will react to the coiling
04	**Operative**	The combination and deployment should be designed in a manner which makes it intuitive, easy and safe to use. **Goal: The combination and deployment should be simple and safe to use**	Combining in horizontal will ease the working conditions, it is easier for the operator to change spools and drums

Table 6: The results linked to the requirements

Kelp Loss Provocation

The full test is presented in chapter 19.3.

Hypothesis

By using the extractor, combining seeding line and carrying rope with a rate up to 2 m/s, without kelp spores being thrown off, because of throw in the seeding line.

Summary

- Small amount of kelp spore loss when tying seeding line to the carrying rope.
- Combining rate up to 2 m/s if feasible.

Conclusion

- There seems little to no loss of kelp spores from combining rates up to 2 m/s.

No.	Name	Description and goal	Result
01	**Rate**	*Meter kelp line deployed per hour* **Goal: Combining with a rate of 1 m/s** **Goal: Deployment with a rate of 1 m/s**	Combining in a speed of 2 m/s
04	**Handling**	It needs to be as little handling of the seeding line as possible. **Goal: Minimum amount of handling of the kelp spores through the process**	No loss of kelp spores during combining with a rate of 2m/s

Table 7: The results linked to the requirements

Multiline Combination

The full test is presented in chapter 19.4.

Hypothesis

It should be possible to combine using the extractor in parallel, and use multiple drums simultaneously by connecting them to a shaft and use it as a drivetrain.

Summary

- Combining using the extractor in parallel
- Tested using manpower, drums and shaft as drivetrain.
- Coiled kelp line onto three drums simultaneously.

Conclusion

- Combining multiple ropes in parallel is beneficial for efficiency since it increases production volume. It is feasible.

No.	Name	Description and goal	Result
01	Rate	*Meter kelp line deployed per hour* **Goal: Combining with a rate of 1 m/s** **Goal: Deployment with a rate of 1 m/s**	By combining in parallel, the rate of kelp line produced, is tripled
04	Operative	The combination and deployment should work in a manner that makes it intuitive, easy and safe to use. **Goal:The combination and deployment should be simple and safe to use**	Feasible to operate three extractors in parallel

Table 8: The results linked to the requirements

Survival Test Drum

The full test is presented in chapter 19.5.

Hypothesis

Kelp spores should survive being coiled onto a drum and stored in a cool dark environment for 24h.

Summary

- 50meter of kelp line stored on a drum in a dark environment ($T<15$ and $T>5$ degrees celsius)
- Drum wrapped in plastic foil

Conclusion

- The kelp spores survived being stored for >24h.

No.	Name	Description and goal	Result
04	**Handling**	It needs to be as little handling of the seeding line as possible. **Goal: Minimum amount of handling of the kelp spores through the process**	The kelp spores survived being coiled on a drum for 27h

Table 9: The results linked to the requirements

Periods

The full test is presented in chapter 19.6.

Hypothesis

It is possible to change the period of the seeding line by enlarging the diameter of the seeding spool.

- There seems to be little to no variation in period length depending on which section of the seeding spool the line is pulled from.
- The period varies depending on diameter of the seeding spool, since the radius will affect amplitude.

Summary

- Different PVC-tubes give different periods
- Tables of lengths kelp line with different diameter on the seeding spool

Conclusion

- Reducing the seeding spool diameter, will result in smaller periods.

Pipe diameter	**63mm**	**50mm**	**32mm**
Average periods rounded to integer	**20cm**	**15cm**	**9cm**

Table 10: Diameter of the seeding spool and the period

No.	**Name**	**Description and goal**	**Result**
06	**Harvesting**	Facilitate for low faulty production, increase production volume and a less time-consuming harvest of kelp. **Goal: Facilitate for harvesting**	Related to the 19.1 testing Different diameters of the seeding spool, gives different periods

Table 11: The results linked to the requirements

Asphalt Seaweed Shuttle

The full test is presented in chapter 19.7.

Hypothesis

We assume deployment rate of 10km/h could be achieved by having drums in parallel during deployment, and that having carabine hooks replacing knots and splicing.

Summary

- There is a need for resistance on the drum shaft for the rope to be in tension, during deployment.
- Splicing rope ends and connecting floating elements with carabine hooks takes an average of 16 seconds compared to 39 seconds when splicing by knots at the In field - combination and deployment test, chapter 19.1.
- A deployment rate of 15 km/h was achieved.

Conclusion

- Deployment with drums in parallel seems feasible and more efficient compared to singular drum deployment.
- A brake system to control the rotational speed of drums during deployment and to hold the ropes still when changing splicing rope lengths, needs to be designed.
- The option of having the rope ends from deployed drums connected in series with floating elements and the next drum should be further investigated.

No.	Name	Description and goal	Result
01	**Rate**	*Meter kelp line deployed per hour* **Goal: Combining with a rate of 1 m/s** **Goal: Deployment with a rate of 1 m/s**	Increasing the efficiency by deploying in parallel Deployment rate of 15km/h of the car
04	**Operative**	The combination and deployment should be designed in a manner which makes it intuitive, easy and safe to use. **Goal: The combination and deployment should be simple and safe to use**	It is feasable to operate three drums during the deployment at the same time
05	**Connection**	Quick connections between ropes, floating elements, and to framework in the sea that are reusable **Goal: Reduce time used for connecting**	Connection of ropes/splicing and fastening buoys : 16sec

Table 12: The results linked to the requirements

Rates based on test results

The rates for combining and deployment comes from (Multiline Combination, chapter 19.4 and Asphalt Seaweed Shuttle, chapter 19.7).

The combining and deployment rates are multiplied by the number of drums in parallel, which is then multiplied with a reduction factor of 15% to include time spent on logistics. In this case, transport back and forth from farm, lunch breaks, moving drums into deployment rack, connecting floating elements and rope ends together are some of the activities which go by the term logistics.

Deployment	**Value**	**Unit**
Singular deployment rate	1.5	m/s
Parallel deployment rate	6	m/s
	21	km/h
Reduced rate	**3**	**km/h**
Combining		
Singular deployment rate	1.4	m/s
Parallel deployment rate	6	m/s
	20	km/h
Reduced rate	**3**	**km/h**

Reduction factor:	0.15
Drums in parallel:	4

Table 13: Rates based on test results

The results seems to indicate that both the combining and deployment rate could increase proportional with number of drums in parallel, and that one then by having 4 drums in parallel for deployment could multiple today's (average deployment rate throughout a work day) of approximately 0.5 km/h by **a factor of six**, theoretically. One need to keep in mind that adding drums increases complexity as well, which could result in a lower actual rate. The goal of singular combining and deployment rates >1 m/s are met, with the reduction factor included. These rates are only an indication, and not representative for the actual rates during at deployment, which might be lower due to unforeseen complications.

14 Discussion and reflection

This chapter is meant to illuminate the process from different points of view, and bring out different thoughts and theories about a case.

14.1 Execution of the project

The thesis plays out within a broad subject. The kelp industry is still at an early stage, and there are a lot of uncertainties. The thesis is at the intersection of mechanical engineering and marine biology, which challenges our task as mechanical engineers. Throughout the project, the group has acquired a lot of knowledge related to the biological aspect of the combining and deployment processes in the kelp industry. It has been exciting.

The groups impression of what the kelp spores can withstand, is related to uncertainty. Throughout the project, our understanding of the handling requirement has developed. In the beginning, our impression of the kelp spores being so vulnerable, that they should not be touched at all during the combining and deployment. After testing, research, conversations, and discussions with marine biologists from Seaweed Solutions, the kelp spores are not that vulnerable as the group originally thought. The first meeting with our supervisor from Seaweed Solution said, "The devil is in the details", and that sums several uncertainties up.

Testing has been a major part of the decision basis in the project. There have been sources of errors related to the testing - human errors when combining and using human power for instance. Testing is not repeated enough times, so the amount of data is lacking in most cases. On the other hand, the tests have been important for the group to make decisions and to get an impression of how different concepts and ideas work in practice.

It should be taken in mind that other standards can as well provide an equally good result, but this will not be taken much into account. Some of these standards are developed over the course of a decade, and we find it appropriate to let the expertise of the company determine these factors. At the same time, we will develop our solution in a way that makes it usable with other standards.

Learning objectives

The main learning object has been to acquire practical use for knowledge related to the mechanical engineering field. As a result of the thesis being interdisciplinary, not all bullet points for learning objectives set by the group at start was met. This is a list of the learning outcomes the group wanted to achieve through the thesis.

1. Learn about new product development processes
    - All members of the group concur that the learning objective was met.

2. Get knowledge about collaboration in a project.
    - From before, the group consisted of three friends. After hours of hard work and a now having carried out their thesis, it is certain that they all have gained insight in project work.
3. Learn how to write a thesis, and see understanding of how software can contribute to the thesis in a positive manner.
    - Through the final stages of writing, the group felt some frustration towards the LaTeX-format, mostly because of a hard time formatting tables and illustrations. Still, the learning process was insightful and the result rewarding.
4. Acquire knowledge on how to develop an efficient production.
    - By implementing different strategies and methods for streamlining, the group met the objective
5. Expand the vocabulary within technical English
    - By writing and formulating the report in a different language than the mother tongue, the group was challenged and undoubtedly learned new expressions. It may be that the group would have written differently, and in some contexts more precise manner, if they had had the thesis in Norwegian. However, since the group has worked with an international team, it became natural to try their hand at writing as well.
6. Set up feedback loops for sensors implemented in final concepts.
    - Since the task went broader than first expected, the group concluded that goining into such details was unnessecary at this point in the developement process.

14.2 Development process

The development process has been divided into four different stages. In reality, the process has been more fluid, and many ideas have been rejected towards the final concept. A brief evaluation of each stage will be described. This chapter will take a closer look at the various decisions that have been made along the way.

Stage 1 (Combining technique):

Even though the concept is presented as a new technique, it is important to note that the method for combining is not new. It was looked into other methods, but none of the other concepts provided the desired results. The conclusion was therefore to build on a method that already exists. It can be discussed what is really new with the concept, here it has been concluded that the method is known, but that the framework around the method is new.

Stage 2 (Operating conditions):

Deciding that the combining should happen on land has had a big impact on the project. As the task initially was to make a machine that would be placed on a boat, that project took an unexpected turn when moving to land. It was considered the best option to be able to meet the requirements that have been set. It should be noted that doing the combination on land depends entirely on the survival of the kelp spores. It was completed one survival test with a positive result, but to verify that it works, a more in-depth test should be done.

Stage 3 (Function parts):

To be able to present a combining concept, a number of functions as described. 6 different functions needed to be described, and some with different concept variations. In retrospect, it can be said that the various functions were not developed carefully enough. It was not presented a concept generation of each function. It was only presented the concept variations that were tested. This was done so that one could more clearly keep a common thread throughout the task. This is a bit contrary to how to proceed with product development.

Stage 4 (Deployment technique):

The deployment part of the project was not developed as much as desired. It was desirable to develop a full-fledged technique. It lacks some details regarding connection and floating elements. It was decided that this field was too large to complete in this thesis. However, there was done some research and it was concluded that it should be solutions that fit the demand regarding this.

Final concept:

The results from the final concept are presented in chapter 13. Measurements related to the rate, are associated with uncertainty. We have tried to come up with exact data, to compare the efficiency - which has proven to be more difficult than first thought. We have nevertheless made an attempt, and presented it. An excel sheet, with many factors, has been made, but it is complex and is not used directly in the thesis. Excerpts can be seen in chapter 67.

The final concept is a proposal for a method, which can be applied on different scales. A project, which has been of our interest, is the MacroSea-project [6]. Automation of the cultivation process is an outcome of the project. There are a few steps until the industry is ready for this step. Our thought is that our final concept is a step in the right direction.

15 Conclusion

01 Rate

The deployment and combining rate of were met, based on results from testing.

02 Contact Surface

The goal of having a continuous contact surface was reached based on visual inspection of test results.

03 Handling

Kelp line survived being stored on land for 24 hours, which could indicate that the handling requirement is also met, but this should be tested more thoroughly.

04 Operative

The requirement set for combining and deployment to be simple and safe was met during testing, but a fully working concept must be developed to establish this.

05 Connections

It is found potential in reducing the total time used for splicing and connecting buoys with a connection that meets the requirements, but needs further testing while at seas to validate if this is true in the working environment as well.

06 Harvesting

The final concept facilitates the harvesting process, where operators could have a seemingly continuous harvesting pace, which could also reduce faulty production from loss. Regarding the kilograms wet weight per meter, the final conclusion will come when harvesting is done.

The given task prior to the thesis was to design a machine that would combine a seeding line fertilized with kelp spores and a carrying rope, making the process at sea more efficient. The task at first consisted of making a machine that would combine and deploy kelp line continuously. Through testing and consultation, it was concluded that dividing the combining and the deployment was essential to reach the goal of making the deployment at sea more efficient compared to today's method.

The proposed concept combines the seeding line with a carrying rope on land. The extractor concept was the chosen method to produce kelp line in a satisfactory manner, which is prepared on drums ready for deployment. The concept results in a demand for more work on land but could decrease the job while deploying at sea.

The requirements set related to the development process have been partly met.

The combining machine is thoroughly tested. Regarding deployment, connections and harvesting there still are some missing conclusions.

Under controlled circumstances, there are indications that the functional model can be up to six times as effective at deployment measured against the current method. There are several factors that play a role in this value and thus great uncertainty about the result. In the absence of quantitative data, the group does not want to call the result more than an indication that the technique works. Based on this indication, it may seem that the bottleneck for kelp farming is no longer in the deployment process but has been moved on to harvesting and raw material processing.

Quantitative data are needed to determine how the concept works under current working conditions before the indication can be verified. Based on feedback from Seaweed Solutions, the final concept will be considered implemented in future seasons. Some aspects need further development in advance of this.

16 Further work

The results from the thesis is mostly conceptual proposes, all parts of the concept will therefore need further detailing and refining. The thesis scratches the surfaces on different topics related to seaweed cultivation, which needs further investigating. A list over the aspects that will need to be further detailed is presented:

- Set dimensions of the combining production, making it ready to be constructed.
- The development process needs further testing- how many is sensible to have in parallel and test different connection mechanisms
- Further testing of survival of kelp spores while being on drums.
- Research the potential related to variable periods and its affect on the harvesting result.
- Developing of floating elements that meets the demand for the new deployment method.
- Develop the construction that will be placed on the boat, which will store the drums and deploy kelp line.
- Develop a way of sealing the drums to create the right conditions for the kelp spores under transport.
- Look into how the harvesting method must change to fit the new deployment method.
- LCA-analysis

  In total, it is necessary to gain more experience from using the concept and see the results.

PART V

METHODS AND THEORY

17 Limitations of the project

COVID-19

During the project period, the global pandemic due to COVID-19 has created limitations for our project. Different infection control rules have caused some obstacles related to the development of the project. We have not been assigned an office to work at, which led to a lot of individual work from our own apartments. We've also been denied to visit different companies and organizations. Mostly we've found ways to cope with these limitations, but it should be noted that the challenges caused by the pandemic have not been ideal.

Biological limitations

Through our project, we've faced problems that have biological uncertainties. When it comes to this kind of uncertainty there are strict rules to maintain a high scientific standard. Many of our choices are based on consultants with the employees as they are the experts in this field.

Time and research limitations

In some parts, we have lacked the time and resources to be able to carry out a quality-assured research test. This has partly forced us to take some conclusion that we ideal would test better and more carefully. For instance, the kelp normally needs months to grow big. The kelp is not ready for harvesting due to the submission deadline. Through our thesis, we will point out any conclusion that may need further testing or where the result is not ready until the kelp has grown.

18 Methods

New product development-process

In a new product development process, referred to as NPD, there are many methods that can be utilized. In this project, we have used different methods that are suitable for acquiring knowledge and carrying out the project in the best possible way. In section , seven points are presented. The project is built on these points. It is important to mention that a NPD-process is an iterative process where evaluation is done consistently, and changes are done accordingly. The process diagram used in the development, illustrates the process.

The following sections will present some of the tools used during the project.

Journal
At an early stage of the project, a decision of which platforms we wanted to use through the project was made. By doing this, we had an overview of all the work done- meeting minutes, thoughts, ideas, sketches, relevant reading material and documentation. All this was posted along the way on Confluence and Google drive. Overleaf was used for report writing. The sketches are drawn in Microsoft OneNote.

Prototyping/function modelling and testing
In order for us to generate insight and validate assumptions made throughout the development process, we early on decided to go for a practical and curious approach. Therefore we have done several test related to the requirements - both for deployment and combining. The tests are not performed in a manner that is worthy of being called scientific, and therefore lack some of the precise descriptions when it for example comes to required equipment, description of process or precise measurements. Their intends are to help us understand the importance of the requirements and how they are connected to each other. In addition the list for sources of error could be further improved.

By using a method referred to as "function modelling", or more frequently used the English term prototyping, the group got to test functions of individual modules from though out the project. Prototyping is often meant to set components in relation to each other to see how the work when put together. Many of the built prototypes are base for further work and understanding. How and from what the function models were built depended mostly on which materials and tools that was accessible in the SES workshop.

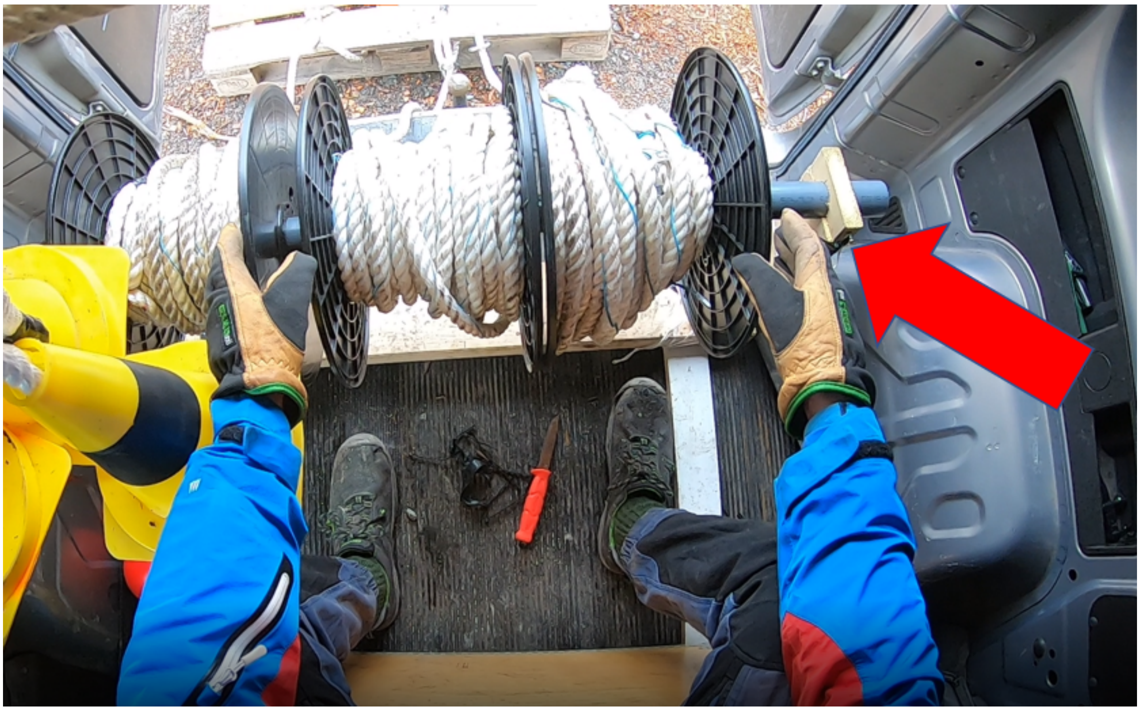


Figure 61: Illustration of a deployment rack prototype, used under 19.7.

Requirements
The conceptual framework are based upon set requirements, which is based on experience from Seaweed Solutions and the groups experience nested throughout the process. Testing and observing have been an important tool for reaching the requirements and importance of the various points.

Tools for streamlining
LEAN and bottle neck principles are commonly used methods for production streamlining. Implementing these two helps eliminate waste, both physical and time, while continuously keeping processes as uncompounded as feasible. Thereby one can also focus on meeting customer needs and reduce frustration among workers executing the process related tasks. The group therefor early on begun speaking with experienced employees for input related to how one could ease tasks and tried to find sources for how problems and waste accrued.

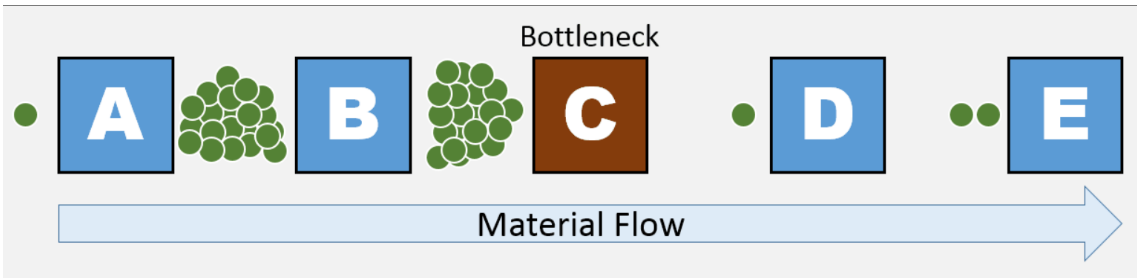


Figure 62: Illustration of how a bottleneck limits a process

PART VI

BIBLIOGRAPHY

19 TEST APPENDIX

19.1 In Field Combining and Deployment

Participants:	Aksel André Wiik Martinsen; Hermann Schips; Mathias Gjone
Test goal:	Compare simultaneous combinining and deployment versus a separate option with storing device.
Relevant requirements:	Rate Contact surface Handling Operative Fastening mechanism Harvesting
Test duration:	Approx. 8 hours

Hypothesis

When combining, there is a period that give the best result for kelp growth.

Summary

- Deploying already combined line was less time and energy demanding than using the Extractor at seas.
- Deploying from buckets was a heavy and space demanding method.
- Combining parallel seeding line to carrying rope did not give a sufficient contact surface.
- Splicing rope and connecting buoys takes approximately 39 seconds per.
- Direction of spinning the seeding line on the carrying rope against "threads".

Conclusion

- Based on the results and discussion with Seaweed Solution, simultaneous combining and deployment is inefficient when splicing, changing seeding spools and connections for buoys. As a result, we will look further into dividing these two operations for further development. Direction of the seeding line spun on the carrying rope will be against "threads" to keep periods consistent.

Testing

Land:
Combing at land with the Spinning Johnny method, and the combined line will be stored in buckets filled with water until deployment. We will test different variations of how the lines are combined in the following order:

Rope 01, Turning in the direction of threads Hypothesis
The seeding line will fall naturally into the pits on the carrying rope.

Part A - Period 200+/- 50 [mm]

No C-rings

Part B - Period 100+/- 25 [mm]

No C-rings

Rope 02, Two parallell vector lines Hypothesis
Fastest method of combining on land.

Part A

C-rings with 1000 [mm] spacing

Part B

C-rings with 500 [mm] spacing

Rope 03, Turning in opposite direction of threads Hypothesis
The seeding line will not be as tight, because of the pits on the carrying line.

Part A - Period 100+50/-20 [mm]

No C-rings

Part B - Period 150+/- 50 [mm]

C-rings with 500 [mm] spacing

The reason for the variations of the periods, is to gain experience to reach the most kilograms of wet weight seaweed when harvesting.

We want to test two concepts when the seeding line is connected in parallel to the carrying rope.

- Connecting one seeding line parallel with the carrying rope. In this scenario, we would try to vary two different factors. We want to vary the distance of the clips, to see how it will influence the growth of kelp. This is to see if the kelp is capable to grow if the seeding line does not have a contact surface with the carrying rope.
- We would also look at the opportunity to connect two different seeding lines to the same carrying rope to increase the number of kelp growing on the carrying line. We would like to try some of the different varieties from the point above, to this testing. Especially the length between the clips.

Sea: The other section is using the Extractor directly into the farm.

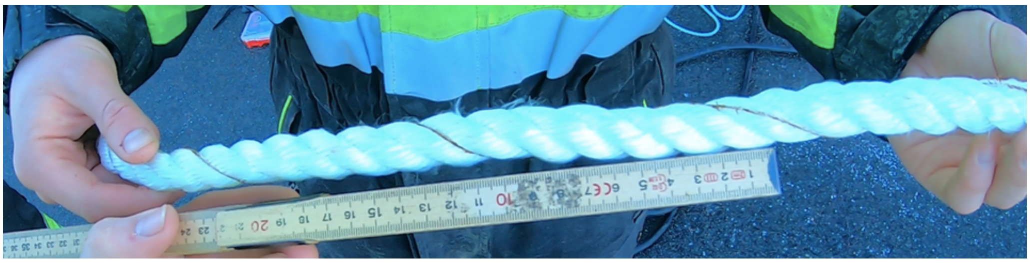
Combination testing

Spinning Johnny at land

Comments and observations:
01. Turning with the threads on the carrying rope: When turning the seeding line in the same direction as threads the seeding line got buried inside the carrying rope in such a manner that both the group and workers from Seaweed Solutions think that there will be less sunlight reaching the kelp spores, which again could result in less growth.

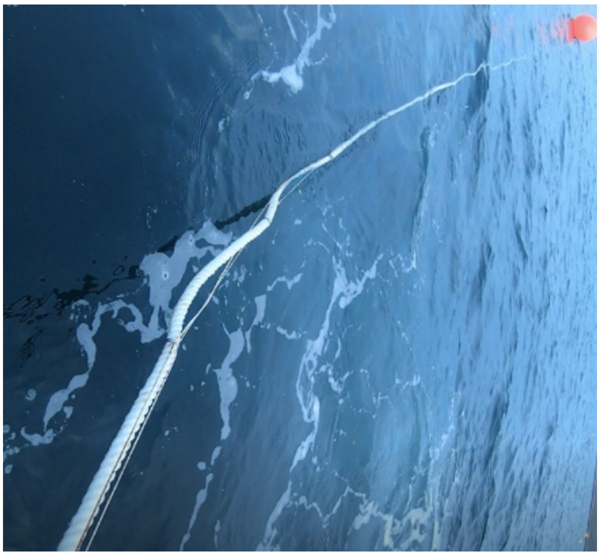
02. Different periods on the rope: With periods of 10+/- 5 [cm] we are confident of coming near a sweet spot for both speed of combining, and the period is getting close to the saturation point for how many plants that are able to grow big without "stealing" the sunlight and resources.

03. Turning against threads in the carrying rope: The seeding line was tight connected to the carrying rope. As stated in 01., the seeding line will be more exposed to light and will get a better result.



Parallell lines combined at land

Comments and observations:
No noticeably increment in speed.The speed achieved for combination was not higher than any of the other methods. It was some instances were the seeding line was fastened with C-rings so tight that the seeding line became the carrying structure in waters. See the picture below.



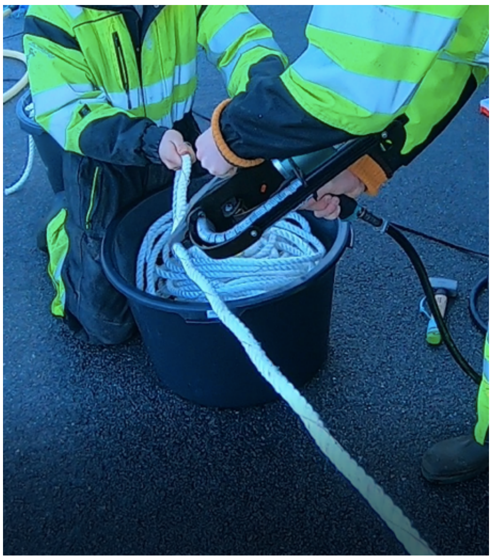
Pulling-through directly into the sea

Comments and observations:
In advance we thought it would be favorable to combine directly into the sea. This was not the case. Even in optimal weather conditions, changing seeding spools and splicing, is a challenge at sea.

Fastening

C-ring machine

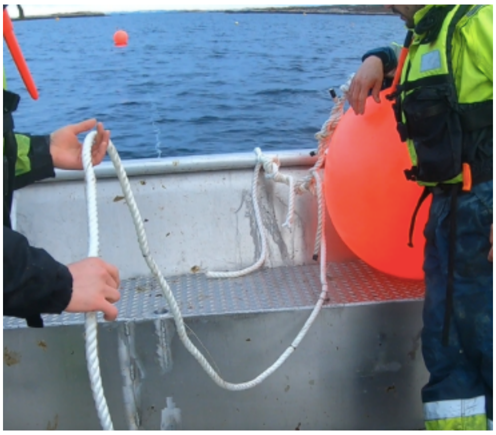
Comments and observations:
Either the C-ring machine or the operator was way to slow. Seeding line was often clamped onto the carrying rope, so that a fixed point of connection could work as a “reset” if the seeding line breaks. For the resetting purpose, it did not work because of too wide C-rings.



Connection by knots

Comments and observations:
A feasable way for fastening buoys and the ropes to the framework. The GoPro-videos made it possible for us to measure the average time spent splicing, and fastening the buoys.

- Connection of lines and splicing (27-34 seconds)
- Fastening buoys (7-11 seconds)



Collecting the combined line

Bucket test

Comments and observations:
In advance, we thought the kelp line would survive in buckets filled with salt water. During deployment a visual check was made and the marine biologists from Seaweed Solutions, concluded that the kelp spores were still alive. The final results will come from inspection during harvesting during summer.

Final kelp line into the sea

Comments and observations:
The technique we used for deployment, is not optimal related to the handling requirement. We used our hands to deploy the rope. It needs further investigation. It is a clever to have the kelp line ready for deployment when leaving the dock.

Conclusions after testing

After testing, summarizing and discussion we fell onto conclusions in collaboration with workers from Seaweed Solutions to most of the uncertainties. We got left with experiences on how the pulling-through-method and spinning johnny works. By evaluating the results and experience from the testing, combining seeding and carry rope on land and bringing a product ready for directly deployment into the farm - either in buckets, taks or large spools, is a method the group want to investigate further.

The group and Seaweed Solution decided that Rope 03 (spinning the seeding line counter-threadwise is the way to go further with)

Next steps

Need further testing of how we can collect kelp line.

To get most insight of the testing, the harvesting is interesting. The harvesting will take place after the thesis is delivered.

19.2 Combination variations

Participants:	Hermann Schips; Mathias Gjone
Test goal:	Determine how length and orientation of seeding spool affects contact surface.
Relevant requirements:	Handling Operative Contact surface
Test duration:	Approx. 2 hours

Hypothesis

Different orientations of the seeding spool will give a variation in combining tension.

Summary

- Friction between seeding line and seeding spool makes combining tension and contact surface sufficient, independent from orientation.
- Friction seems to increase proportional to **L** in **Figure 63**, resulting in a greater resistance as the carry rope gets pulled through.

Conclusion

- Based on the results and discussion with Seaweed Solutions, the desired seeding spool size will be 700 mm long and a horizontal combining method to ease working conditions.

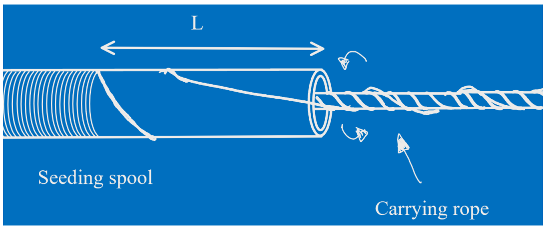


Figure 63:
Combining tension seems to be proportional with the length **L**

Combination testing

Horizontal clamping, seeding spool Ø63.3

Hypothesis
The horizontal way of combining should give a sufficient contact surface than a vertically orientated.

Comments and observations:
The horizontal way of combining the rope and line was easy to operate. The combination-process is then in a upright standing work height, which is well suited for operators in an ergonomic perspective. The further "out" (right direction un illustration) on the spool one combined from, the looser combining tension. This is not wished for since it reduces total contact surface. When pulling the kelp line we observed that the seeding line had the side with kelp spores pointing outwards. We think is wished for since it could result in kelp spores being more exposed for sunlight than if the line is pointing the other direction, resulting in better growing conditions.

Horizontal clamping, seeding spool Ø55mm

Hypothesis
The horizontal test with smaller diameter will result in shorter periods than with Ø63.3

Comments and observations:
To investigate the affect of the diameter of the seeding spools have, we tested with Ø50mm seeding spool. On the picture below we can see that the Ø55mm (upper rope) have about 150mm long periods and Ø63.3mm (lower rope) have closer to 200mm periods. The loner periods, the less total contact surface between line and rope. Seeding spools with larger diameter is therefore undesirable in the context of maximizing contact surface.

Combination testing

Vertical-up

Hypothesis
The idea is that the gravitation force is working parallel with the magazine will result in more even period distribution than horizontal. Basis for assumption is that the gravitational force could accelerate "throw" in line when leaving spool - like a skipping rope.

Comments and observations:
We thought if working in parallel with the gravitational force, we would eliminate throw in the seeding line during the combination, but the result was seemingly identical with the horizontal way of combining. It is notable that the vertical orientation makes the process more difficult when not sufficiently clamped.

Vertical-down

Hypothesis
The idea is that the gravitation force is working parallel with the seeding spool and in the same direction as our carrying rope when combining, which might be exploited for a drivetrain for this process.

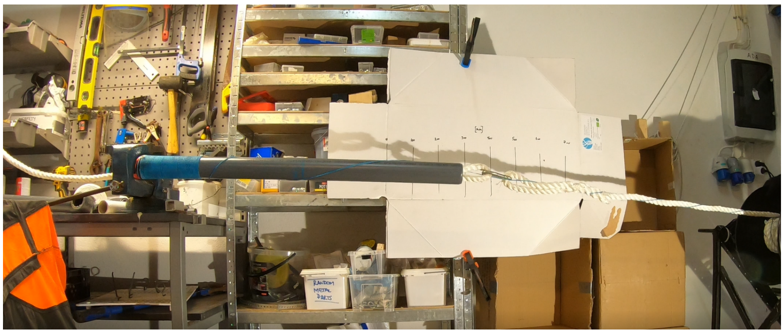
Comments and observations:
Result is more or less the same as for the vertical up test. There is not sufficient basis for concluding the assumption that one can facilitate the gravitational pulling method as a drivetrain instead of man power.

Combination testing

Horizontal with long 1000mm seeding spool

Hypothesis
The further in on the spool we get, the more friction there will be between seeding line and spool, increasing the risk for friction loss of kelp spores while combining.

Comments and observations:
At the end of the seeding spool we could see that the seeding line started to have problems with loosening. This resulted in the seeding line jumping off in a non-continuous way, and resulted in irregular periods which again could result in less total contact surface. The further in on the spool one combine from does not seem to affect how much of the kelp spores that might fall off. Therefore one needs to do more testing in order to conclude if that is the case.



Storage of kelp line

Drum

Hypothesis
Using a shaft, electric motor and drum could be used as drivetrain for combining, and storing combined line on a drum will not harm the kelp spores more than tolerable.

Comments and observations:
The drum in combination with a electric motor and shaft works as assumed.The carrying rope naturally fell in place on the drum. When being dragged out from the seeding spool the kelp line seemed to have suffered no form of loss in the tightening. Our only concern is if the kelp spores will survive being pulled onto a spool like this. Requires survival testing when on drum.

Conclusions after testing

After testing, summarizing and discussion we fell onto conclusions in collaboration with workers from Seaweed solutions to most of the uncertainties. We got left with experiences on how the pulling-through-method works.

- Does difference in angle/direction of the magazine change the result?

  -Yes it does, the result seems to worse (meaning less tight turning) the closer one are to the deployment edge on the seeding spool. After consulting with SS we have come to an conclusion to not use magazine longer than 700mm. This will help to avoid the unwanted result we get from the longest seeding spools. 700mm will then be the total length of the spool, not the length of spun seeding line against it.

- Does the result change when using long magazine (1000mm) if so, at what length does the result change?

  -Yes it does, the result seems to worse (meaning less tight turning) the closer one are to the deployment edge on the seeding spool. After consulting with Seaweed Solutions, we have come to an conclusion to not use seeding spools longer than 700mm. This will help to avoid the unwanted result we got from the 1000mm seeding spools. 700mm will then be the total length of the spool, not the length of coiled seeding line against.

- Is there any speed concerns?

  -We did not observe any big concerns regarding production speed. The test was done by hand there was hard to provoke a high speed test. Since the process is likely being done at workshop, dock or barge, the speed is not critical. If there is a need of faster production it would probably be easier and faster to set up more parallel process lines.

- How capable is the finished rope to be stored in buckets/drum etc?

  -After testing with drum we see that the result is good. It is a concern that using drums can tear of many of the kelp spores. The drums simplify the whole process so much that we are willing to sacrifice part of the kelp spores just to keep it on the drums. Marine biologist from Seaweed Solutions found it really interesting and pointed out that they also saw the biggest potential in using these kind of drums.

- The drum will work as a winch, and coil the kelp line. It will be possible to change the speed by using an electrical motor.

Next steps

- Need further testing of survival of the kelp spores when being coiled onto a drum.
- Need testing related to seeding spools, and how the diameter affects the periods.

19.3 Kelp Loss Provocation

Participants:	Hermann Schips; Mathias Gjone
Test goal:	Determine kelp spore loss combining is related to combining rates up to 2m/s
Relevant requirements:	Rate Contact surface Handling
Test duration:	Approx. 2 hours

Hypothesis

One could combine seeding line and rope with a rate up to 2 m/s without kelp spores being thrown off, because of throw in the seeding line.

Summary

- Small amount of kelp spore loss when tying seeding line to the carrying rope.
- Combining rate up to 2 m/s if feasible.

Conclusion

- There seems little to no loss of kelp spores from combining rates up to 2 m/s.

Test procedure

- Turn on cameras to get reading of time usage and handling
- Pull units of carry line trough the combination device with different speeds (approx.): slow(1.0m/s), medium(1.5m/s) and fast(2.0m/s)
- Film the drums and inspect color, length and overall well being for the plants (collecting data)
- Set up the combining process where one can tell how if plants falls off during the combining (in our case a white isopor box)

Combining testing

Kelp spores during combination

Comments and observations:
The overall impression is that the speed does not affect the loss of kelp spores. When dragging the carrying rope with a speed of 2m/s, we could not observe any kelp spores getting thrown off. The only concern if the speed is too high, is the throw of the seeding line, which affects the attachment to the carrying rope.

Conclusions after testing

The hypothesis matched the results, even when we pulled rope through with a speed of approximately 2m/s, the kelp spores stayed attached to the seeding line. This is based upon watching the GoPro-videos in slow motion. In the picture there are some kelp spores in the isophor-box, but the amount is so small. The loss of plants came while fastening the seeding line to the carrying rope.

19.4 Multiline Combination

Participants:	Aksel Andrè Wiik Martinsen;Hermann Schips; Mathias Gjone
Test goal:	Combining rope with drums in parallel
Relevant requirements:	Rate Operative
Test duration:	Approx. 3 hours

Hypothesis

It should be possible to combine using the Extractor in parallel, and use multiple drums simultaneously by connecting them to a shaft and use it as a drivetrain.

Summary

- Combining using the Extractor in parallel
- Tested using manpower, drums and shaft as drivetrain.
- Coiled kelp line onto three drums simultaneously.

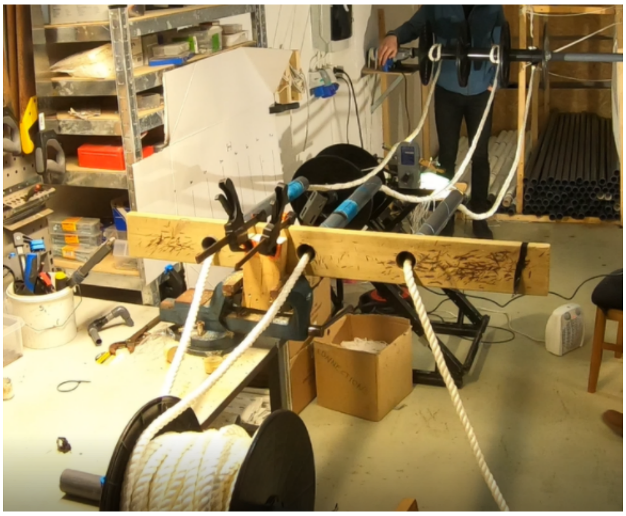
Conclusion

- Combining multiple ropes in parallel is beneficial for efficiency since it increases production volume. It is feasible.

Combining

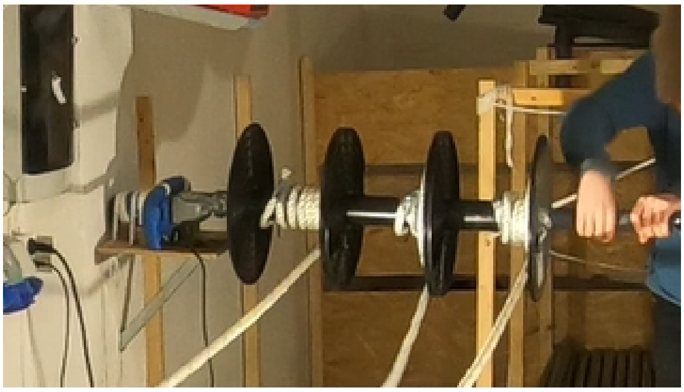
Parallel combining

Comments and observations:
When combining with three pulling through at the same time, we increase the efficiency. The parallel combining worked as intended.



Drums as drivetrain

Comments and observations:
The kelp line was coiled evenly throughout the shaft on the drum. Using drums as a drivetrain for the combining worked surprisingly well. By connecting a motor to the shaft, all the drums will rotate at the exact same speed.



Conclusions after testing

Combining in parallel, multiline combination, is an efficient way of increasing the volume of kelp line produced. The operative benefits of the Extractor, makes the parallel working.

Next steps

Further expansion; more parallel combining units or in series to reduce the periods

19.5 Survival Test Drum

Participants:	Aksel André Wiik Martinsen; Hermann Schips; Mathias Gjone
Test goal:	Survival of kelp spores when stored on a drum for 24h
Relevant requirements:	Handling
Test duration:	30h

Hypothesis

Kelp spores should survive being coiled onto a drum and stored in a cool dark environment for 24h.

Summary

- 50meter of kelp line stored on a drum in a dark environment (T<15 and T>5 degrees celsius)
- Drum wrapped in plastic foil

Conclusion

- The kelp spores survived being stored on land for >24h.

Test procedure

- 50 meter of Ø16mm rope coiled on a drum. The drum was soaked in saltwater. This is a way to ensure a good climate for the kelp spores.
- The 50 meter rope was pulled through the combination device, and onto a drum.
- As soon as the process was done, the drum was packed in plastic foiling to keep it airtight.
- This was leaved for 24+ hours (about 26 hours), before opened.
- From the 50 meters combined line we extracted six lengths of 1-meters line, these 6 lengths were taken from the drum with evenly divided spacing.The six lengths was taken from the following parts (we count from outside and in. So meter 0-1, is the first combined line you pull out of the drum.
  1. 0 meter
  2. 10 meter
  3. 20 meter
  4. 30 meter
  5. 40 meter
  6. 50 meter (last part of the rope)
- These 6 lengths was put in a saltwater pool with the right temperature and light condition.

Storing testing

Combining and packing

Comments and observations:
When the spool was soaked the drum got a lot heavier. The wet spool was not heavier than what an operator could handle - did not weigh them, but lifted one. Estimated weight 5-10 kg. Packing in plastic foil is only a temporary solution. On a big-scale this will lead to huge waste of plastic and is not sustainable.

Opening, dividing and placing the test-lengths in the growing tank

Comments and observations:
After 26 hours, the kelp spores seems fine. The rope is still very wet, this tells us that the conditions have been good for the kelp spores during the 26 hours. There was some handling involved when cutting and mounting the six-lengths to the test-frame. It also

took about 15-20 minutes before the kelp was placed in growing tank after opening. The combined line was not deployed like we would do it into the farm. This have may created an advantage for this test. After placing the ropes in the growing tank, we could observe that the period and tightening still was maintained after the handling. Under water we could see the kelp spores “flowing” free and nicely. It doesn’t seem like that there have been significantly number of kelp spores damaged or torn off. We could not see any difference in the different lengths. The kelp spores is a little longer than what its likely to be used in the ocean. This is because the seeding spool have been in the cultivation pool for a longer period than usual, and should be considered when concluding anything from the test.

Conclusions after testing

We are satisfied with the result so far. The damage of the kelp spores seems to be minimal. We have to check the growth of the kelp spores as close to the deadline of the thesis as possible, to get the best validation of the survival.

Next steps

Explore alternative techniques for how the drums can be stored, instead of plastic foil.

19.6 Periods

Participants:	Aksel Andrè Wiik Martinsen;Hermann Schips; Mathias Gjone
Test goal:	Exploring periods, find the lengths of seeding line combined to the carrying line and how it can be prefixed by changing the spool diameter.
Relevant requirements:	Harvesting Contact surface
Test duration:	Approx. 5 hours

Hypothesis

It is possible to change the period of the seeding line by enlarging the diameter of the seeding spool.

- There seems to be little to no variation in period length depending on which section of the seeding spool the line is pulled from.
- The period varies depending on diameter of the seeding spool, since the radius will affect amplitude.

Conclusion

- Reducing the seeding spool diameter, will result in smaller periods.

Pipe diameter	**63mm**	**50mm**	**32mm**
Average periods rounded to integer	**20cm**	**15cm**	**9cm**

Table 14: Diameter of the seeding spool and the period

Uncertainties

1. Will the period change during combining? Is there any differences between the start, middle and end phase of the combining?

   -*To ensure contact surface, continuous good result under cultivation it is important to ensure that the periods of the seeding line is stable.*

2. Will different diameters on the seeding spools change the periods?

   -*To be able to control the period by changing the spools diameter can be very beneficial.*

3. How many meter of kelp line can be produced from a set length of seeding spool?

   -*Since the seeding spools is produced in the laboratory it can save resource to only produce the lengths that is needed for each carrying rope.*

4. What is the ratio between length of seeding line per length carrying line?

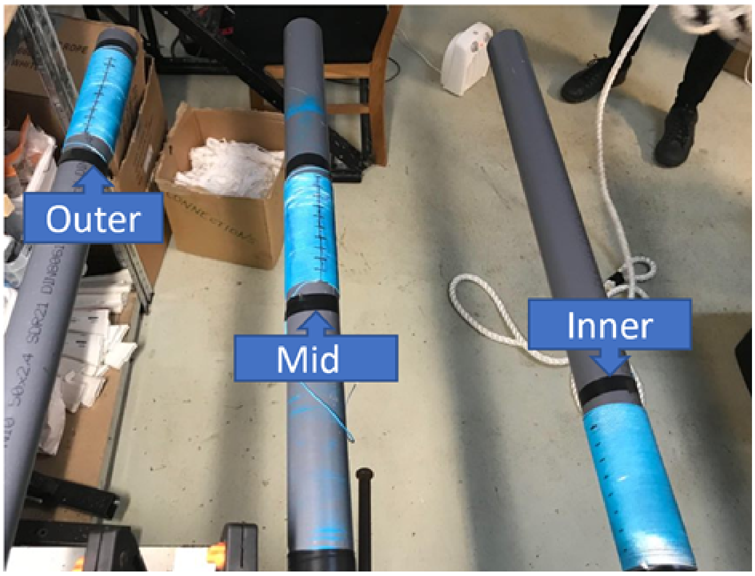
   -*The ratio between seeding line and carrying line can help us tell how much kelp spores is combined to the carrying line.*

Combining results

1. Period during the length of the spool

Hypothesis:
The period will not change as long as the width of the spool is the same.

Comments and observations:
From the testing we marked every 10 rotations of vector line around the vector spool with a marker. We tested three different scenarios. The start (inner), when you are half through the process (mid) and the end (outer). Since every 10th rotation on the seeding spool was marked, we measured the length of the carrying rope between the two marks after combining. There was 7 measuring on each scenario to maintain a good quality on the testing. The total of measured period measured is then 10 rotations * 7 measurements * 3 different stages = 210 periods. This test was only performed with the 50 mm pipe.



Name L - Length P - Period	**Inner (L) [mm]**	**Mid (L) [mm]**	**Outer (L) [mm]**
1.	149	152	149
2.	145	150	150
3.	145	150	147
4.	150	152	146
5.	150	150	146
6.	142	151	146
7.	150	153	149
Test average	**147.3**	**151.1**	**147.6**
	Total average:	**148.7**	

Table 15: Periods from the different part of the seeding spool

The results from table 15, shows an average of one rotation on the seeding spool will give about 15 cm of carrying rope.

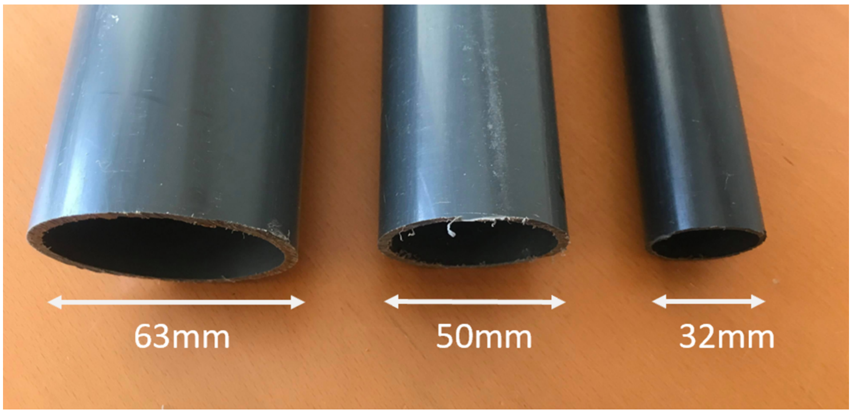
This gives us that 10 rotations on the seeding spool gives about 150 cm of carrying rope over 10 periods.

This shows that the number of rotations on the seeding spool is directly associated with number of periods on the carrying rope.

2. **Will different diameters on the seeding spools change the periods?**

Hypothesis:
The period will change when the diameter of the spool change.

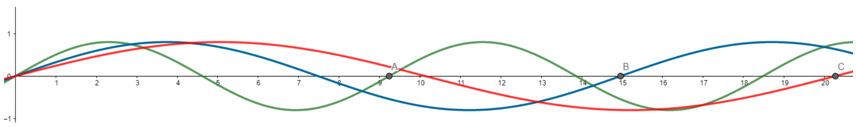
Comments and observations:
For this testing, will the three different sized pipes be. Since 50 mm is the standard, we find it most relevant to test a bigger pipe and a smaller pipe. The other sizes are also considered standard pipes. 50 mm pipe was already tested tested carefully, so the average length from Table 15 will be used. The other pipes was measured in the same way as in table 15, but not in the same quantities.



Period / Spool width	63mm	50mm	32mm
1.	20.5	–	10
2.	19	–	9
3.	19.5	–	7.5
4.	22	–	9
5.	20	–	10.5
6.	20.5	–	9
7.	21	–	9.5
Average period length	**20.4 cm**	**14.9 cm**	**9.2 cm**

Table 16: Periods from different seeding spools

To get a better visualization of how the different periods compared to each have we created a simulation of the periods using the sine wave, which in many way is representable for the seeding lines period. Take in mind that the seeding line revolve around the carrying rope in the 3 dimensional room. We have looked into presenting this be calculating a velocity vector to simulate the path of the line, but we find it a whole lot easier and more accurate to measure in real life.



By presenting the different method with sine waves we can see a good visual difference. The graphs are consisting of:

- The sine wave is presented by f(x)=A*sin(F*x)
- A is the amplitude, since the carrying rope will the amplitude be 1,6 mm/2=0,8 mm
- Dividing 2*pi by the length of the period

Width	**63mm - f(x)**	**50mm - g(x)**	**32mm - h(x)**
Period	20.4	14.9	9.2
2*pi/period	0.314	0.420	0.630
Function	f(x) = 0.8*sin(0.31*x)	g(x) = 0.8*sin(0.42*x)	h(x) = 0.8 *sin(0.68*x)

3. How many meter of kelp line can be produced from a set length of seeding spool?

Hypothesis:
Bigger spools will produce significantly more kelp line.

Comments and observations:
One rotation around the pipe is not a unit, so this has to be measured. When the seeding line is tightly spun around the seeding spool it tends to flatten and get wider. The seeding line is 1.4 mm thick from the factory, but it might be more when spun around the pipe. This measurement is done by measuring different lengths on the spool, and then count how many rotations takes place in this certain length.

Length of coiled seeding spool:	**Number of rotations**	**Width of each rotation**
40mm	27	1.48mm
50mm	34	1.47mm
50mm	34	1.47mm
83mm	58	1.43mm
	Average width:	**1.46mm**

The set length of the pipe is set to 700 mm, as it is the standard.

700/1,46=479 rotations of seeding line on one standard sized seeding spool (700mm)

	63mm	**50mm**	**32mm**	**Formula**
Average period length	20.4cm	14.9cm	9.2cm	From Figure 16
Number of rotations	479	479	479	799mm/1.46mm
Length of kelp line	**97.7m**	**71.4m**	**44.1m**	Number of rotations* average period length

4. What is the ratio between seeding line per carrying line?

Hypothesis:
Smaller diameter will lead to more seeding line per carrying rope.

Comments and observations:
This test is done by measuring up 15 rotations with seeding line on the three different pipes, and marking exactly when the seeding line is spun 15 rotations . The seeding lines is then straighten out and measured. This could also be calculated, but then it would not take in mind the volume of the line it self, and the extra length that is added when moving along the pipe.

Conclusions after testing

1. **Will the period change during combining?**

-No, the test shows that it is no significant change in the length of the period during combining.

2. **Will different diameters on the seeding spools change the periods?**

	63mm	**50mm**	**32mm**
Number of rotations	15	15	15
Total length	306mm	243mm	160mm
Length of one rotation	**20.40mm**	**16.20mm**	**10.67mm**
Length of seeding/length of carrying rope	**1.0**	**1.09**	**1.16**

-Yes the period changes with the diameter of the seeding spool. The bigger the spool the longer the periods.

Pipe diameter	**63mm**	**50mm**	**32mm**
Average periods rounded to integer	**20cm**	**15cm**	**9cm**

3.**How many meter of kelp line can be produced from 700 mm length of seeding spool?**

- The length of kelp line relates to the size of the seeding spools

Pipe diameter	**63mm**	**50mm**	**32mm**
Produced length from 700mm spool	**97.7m**	**71.4m**	**49.4cm**

4. **What is the ratio between seeding line per carrying line?**

- The ratios between seeding line and carrying line increase with smaller diameter on the seeding spool. In reality will the 63 mm pipe have a little longer seeding line, but since the periods are so long it have not been measurable in this test. We do not find it necessary either. We can clearly see the trend.

Pipe diameter	**63mm**	**50mm**	**32mm**
Length of seeding/length of carrying rope	**1.0**	**1.09**	**1.16**

19.7 Asphalt Seaweed Shuttle

Participants:	Aksel Andrè Wiik Martinsen;Hermann Schips; Mathias Gjone
Test goal:	Deploying with drums in parallel
Relevant requirements:	Rate Fastening mechanism Operative
Test duration:	Approx. 4 hours

Hypothesis

We assume that a total deployment rate of 10km/h could be achieved by having drums in parallel during deployment, and that having carabine hooks replacing knots and splicing.

Summary

- There is a need for resistance on the drum shaft for the rope to be in tension, during deployment.
- Splicing rope ends and connecting floating elements with carabine hooks takes an average of 16 seconds compared to 39 seconds when splicing by knots at **??**
- A deployment rate of 9 km/h was achieved.

Conclusion

- Deployment with drums in parallel seems feasible and more efficient compared to singular drum deployment.
- A brake system to control the rotational speed of drums during deployment and to hold the ropes still when changing splicing rope lengths, needs to be designed.
- The option of having the rope ends from deployed drums connected in series with floating elements and the next drum should be further investigated.

Test procedure

- Anchor end to the euro pallet, which is simulating the connection to the framework at sea
- Turn on cameras to get reading of time usage and handling

- Drive the car forwards while deploying combined line
- Redo each test

Deployment

Parallel deployment

Comments and observations:
When deploying three drums at the same time, we increase the efficiency by deploying in parallel. The parallel deployment was working. The operator had to use his hands for braking. It was necessary to give the drums resistance during the deployment. If not, the drums would have spun uneven. A braking system should be implemented.

Speed deploying

Comments and observations:
We had 75m coiled onto one drum. The speed of the car was at it‘s fastest 15km/h. This shows us that it is possible to deploy rope faster than today. If we deploy 3 ropes at the same time, we will have a speed of 30km deployed line/h if the speed is 10km/h! It is also impossible to increase the number of drums, and deploy for instance 5 lines at the same time.

Fastening

Comments and observations:
During the deployment, we stopped every 5 meters and used carabine hooks for splicing, aswell as simulating fastening of bouys. The carbine hooks is a faster technique for fastening compared to splicing. The connection operation went smooth using carabine hooks. From the GoPro-videos, we are able to get some time measurements for how efficient it is compared to splicing.


Conclusions after testing

We wanted to test if carabine hooks are a more efficient way of connecting. After the testing was done, we can by far conclude that it is a much faster method than knotting, based on the time measurements.

We can also conclude with speed when deploying can be 10km/h without causing any problems.

Cutting a cable tie, splicing and fastening a buoy took 12-18 seconds. After this process is done, the next drum is ready for deployment. At Frøya, the same procedure was divided into splicing and fastening buoys, and the same process took 34-45 seconds in total.

Next steps

Design some kind of resistance to the drum shaft during the deployment- develop a braking system.

Risk analysis from the test can be seen in Figure 66.

20 Requirements

Final requirements

01 Rate

Description and goal
Meter of rope per unit of time

Goal: Combining with a rate of > 1 m/s

Goal: Deployment with a rate of > 1 m/s

Discussion
In order for seaweed farmers to increase the annual crop, one need to utilize a narrow time window for deployment. Today Seaweed Solution deploys in a speed of approximately 0.5 km/h. Since combining and deployment could be divided into separate processes, there are two goals.

It is essential with decent combing and deployment speed to ensure an efficient production. Currently, the speed of the deployment is the most crucial in the seaweed-farming-process, because the weather conditions during deployment needs to be calm.

Wind force strength and direction is important for a calm ocean surface. The rate also counts in the time for preparation, adjustments, connecting, breaks, etc. It is working time divided on the length of kelp line produced and deployed. This means that both combining and deployment must happen in a higher rate to make up for all the lost time. The other aspects of combining and deployment is therefore also essential to ensure high rate.

The deployment rate is our main focus, because it is the most critical part of the process. Everything that could be prepared in advance, should be prepared in advance based on the group's and local fishermen's experience.

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02 Contact surface

Description and goal
For making it possible for the seaweed to grow on the carrying line, a contact surface between the seeding line-and carrying rope is necessary.

Goal: The seeding line should have continuous contact with the carrying rope

Discussion
The kelp spores grows on the seeding line in the breeding stage. During growth in the

ocean the kelp spores will grow over to the carrying rope to ensure sufficient attachment. If the seeding line is not in fully contact with the carrying line, the kelp spores may not grow. The same problem can occur if the seeding line moves along the carrying rope, creating friction between the ropes. The seeding line should therefore have contact and sufficient tensile force so that the line and the rope stand still in relation to each other. The needed area of contact surface that is not specified at this stage in research, but based on feedback from SES the more the better, and then one just have to test.

Another criteria is to assure that the kelp spores are placed so that they get a sufficient amount of sunlight (for photosynthesis). Exactly how much sunlight they need on a daily basis is hard to tell, but it is our understanding that the more the better. Therefore we went for having the the fertilized surface of seeding line should be pointing outwards when combining.

What is meant by continuous contact surface, is described with the two figures 64 and 65

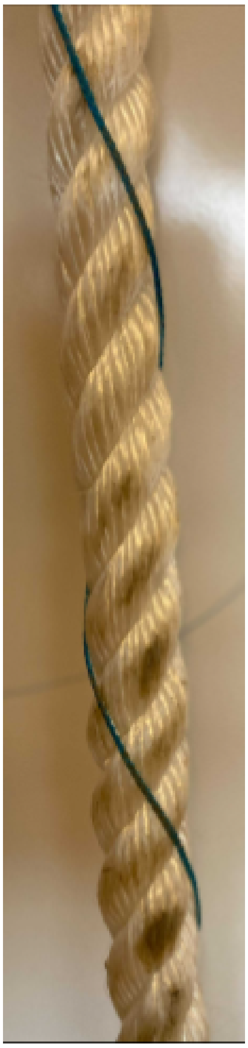


Figure 64: Continuous contact surface

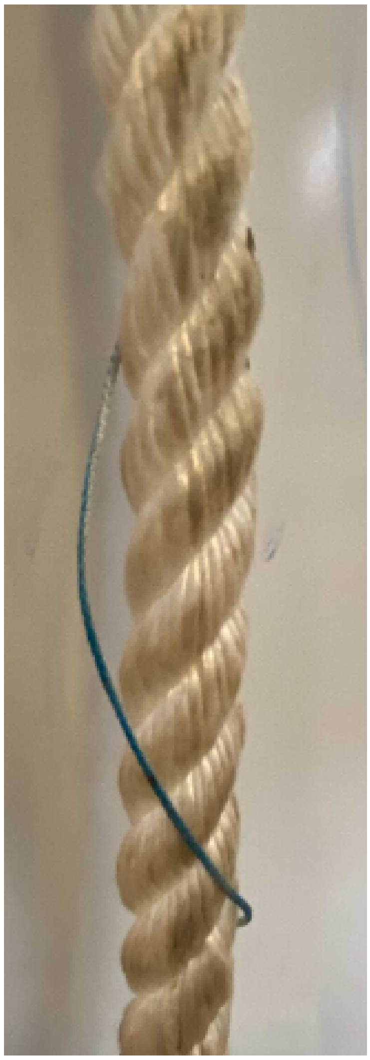


Figure 65: Non-continuous contact surface

03 Handling

Description and goal
There needs to be as little handling of the seeding line as possible

Goal: Minimum amount of handling of the kelp spores

Discussion
Contact : There needs to be as little handling of the kelp spores as feasible. This statement means that optimally, the kelp spores should not be touched by any operator nor touch/scrape anything before or during deployment. Friction is the biggest hazard for loss of kelp spores. Pressure on the kelp spores is also not ideal but considered a better alternative to friction.

Environment : The plants are delicate and vulnerable when it comes to physical weather and contamination. Here is a list of the environmental concerns that can inflict the kelp spores badly:

-Fresh water

-Direct sunlight

-Wind

-High temperatures (17+ degrees Celsius)

It is therefore important that the kelp spools are stored in a cold, salt water environment, isolated from direct sunlight and wind during transport, and ideally under deployment and combining as well.

---

04 Operative

Description and goal
The combination and deployment should work in a manner that makes it intuitive, easy and safe to use.

Goal: The combination and deployment should be simple and safe to use

Discussion
Combining: The combining machine must be easy and intuitive to ensure continuous production and to minimize human errors. The operator must be able to use the machine while using gloves, because of cold environmental conditions. In relation to the working environment law, the machine must be safe to use for the operator.[7].

Deployment: The deployment will take place in either October or January , the conditions at sea is considered very cold and dangerous at this time. The methods for deployment must be facilitated to ensure safe working conditions for the worker. The method should also be intuitive and easy to ensure efficiency despite cold conditions.

---

05 Connection

Description and goal
Quick connections between ropes, floating elements, and to framework in the sea that are reusable.

Goal: Reduce time used for connecting

Discussion
Possibly the biggest time consuming tasks at sea is tying knots to connect ropes, floating elements and framework. Today's method is based on a lot of manual labor from tying these knots. Here are some of the task related to fastening:

1. Splicing rope to each other.

2. Tying floating elements to kelp ropes.

3. Tying kelp ropes to a the framework of the farm.

It is desired to develop solutions to eliminate unnecessary labor at sea. Reducing the time used on these tasks will greatly inflict on the overall efficiency. It is also a prerequisite for further scaling.

---

06 Harvesting

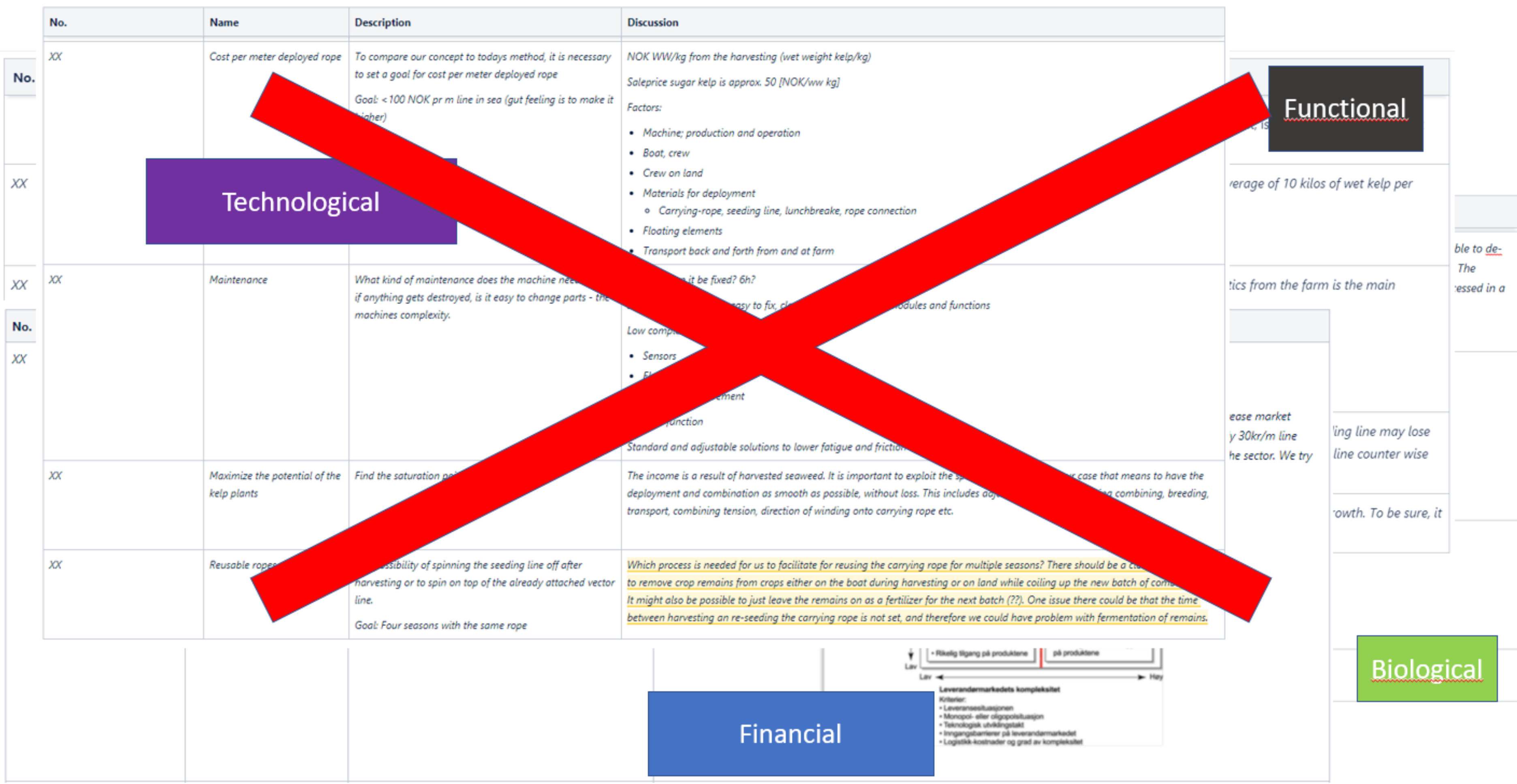
Description and goal
Facilitate for low faulty production, increase production volume and a less time-consuming harvest of kelp.

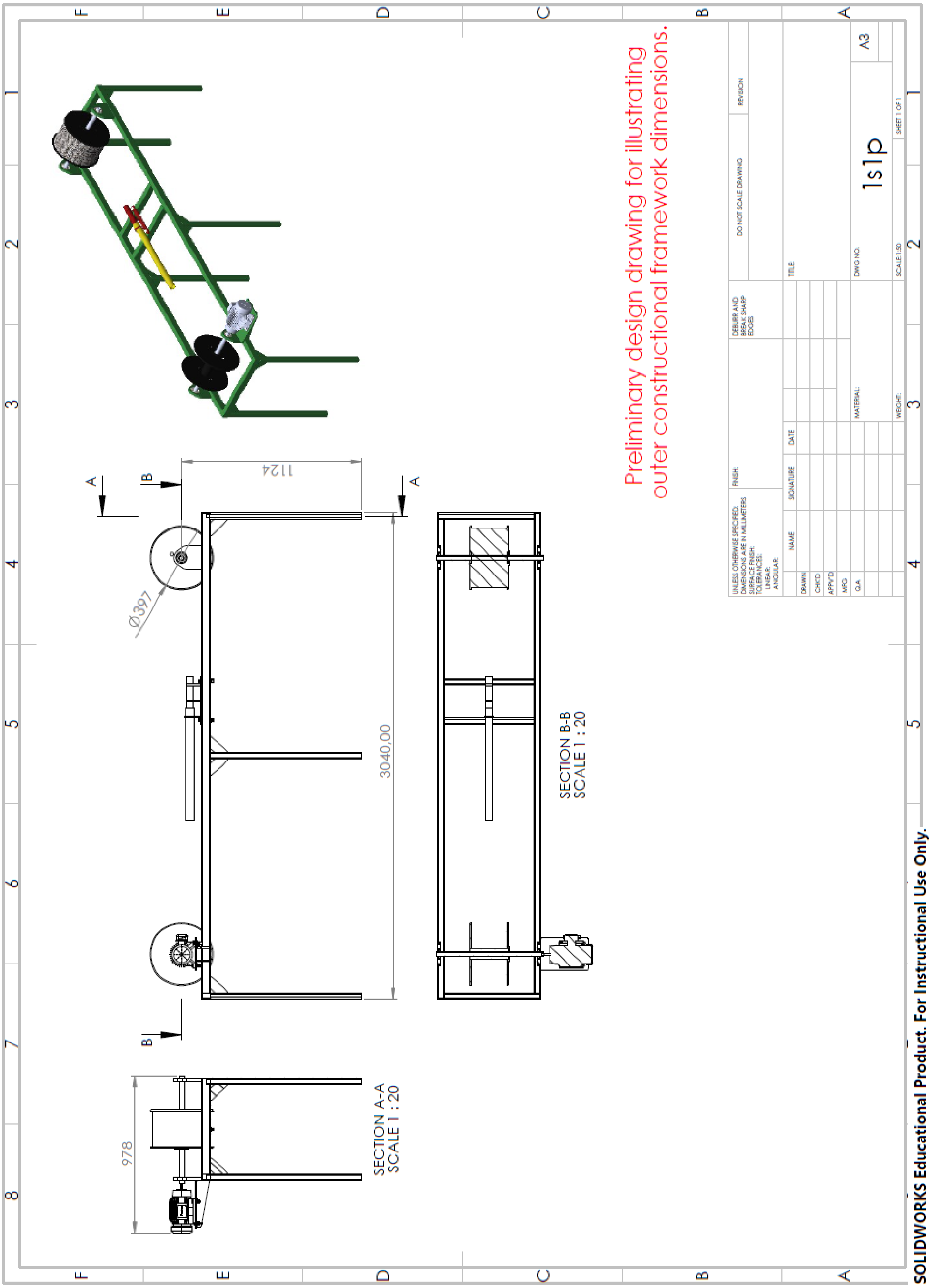
Goal: Facilitate for harvesting

Discussion
Combining and deployment should facilitate for efficient and a result of > 5kg ww/m from harvesting.

To ensure efficient harvesting the kelp lines must be deployed and connected in a pattern which makes it easy to disconnect from the farm and harvest.

The amount of grown kelp on the ropes is important to ensure a good harvesting, the method of harvesting can greatly inflict on the amount of kelp loss under harvesting and thereby increase what would be categorized as faulty production.


Technological
Functional
Biological
Financial
No.
Name
Description
Discussion
XX
Cost per meter deployed rope
To compare our concept to todays method, it is necessary to set a goal for cost per meter deployed rope
NOK WW/kg from the harvesting (wet weight kelp/kg)
Saleprice sugar kelp is approx. 50 [NOK/ww kg]
Factors:
Machine; production and operation
Boat, crew
Crew on land
Materials for deployment
Carrying-rope, seeding line, lunchbreake, rope connection
Floating elements
Transport back and forth from and at farm
Maintenance
Sensors
Standard and adjustable solutions to lower fatigue and friction
Maximize the potential of the kelp plants
The income is a result of harvested seaweed. It is important to exploit the
transport, combining tension, direction of winding onto carrying rope etc.
Reusable rope
harvesting or to spin on top of the already attached vector line.
Goal: Four seasons with the same rope
Which process is needed for us to facilitate for reusing the carrying rope for multiple seasons?
It might also be possible to just leave the remains on as a fertilizer for the next batch (??). One issue there could be that the time
between harvesting an re-seeding the carrying rope is not set, and therefore we could have problem with fermentation of remains.


Preliminary design drawing for illustrating
outer constructional framework dimensions.
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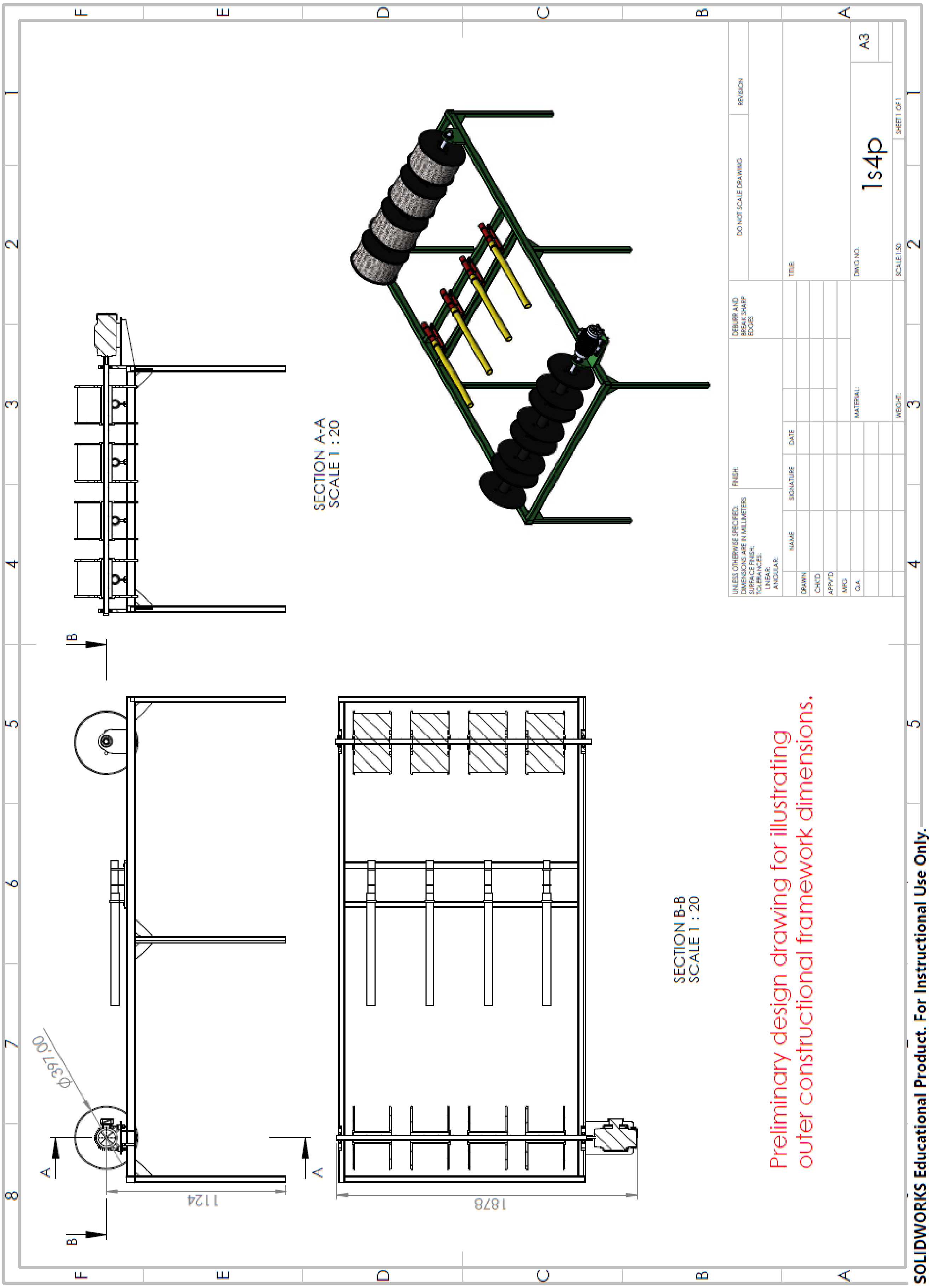
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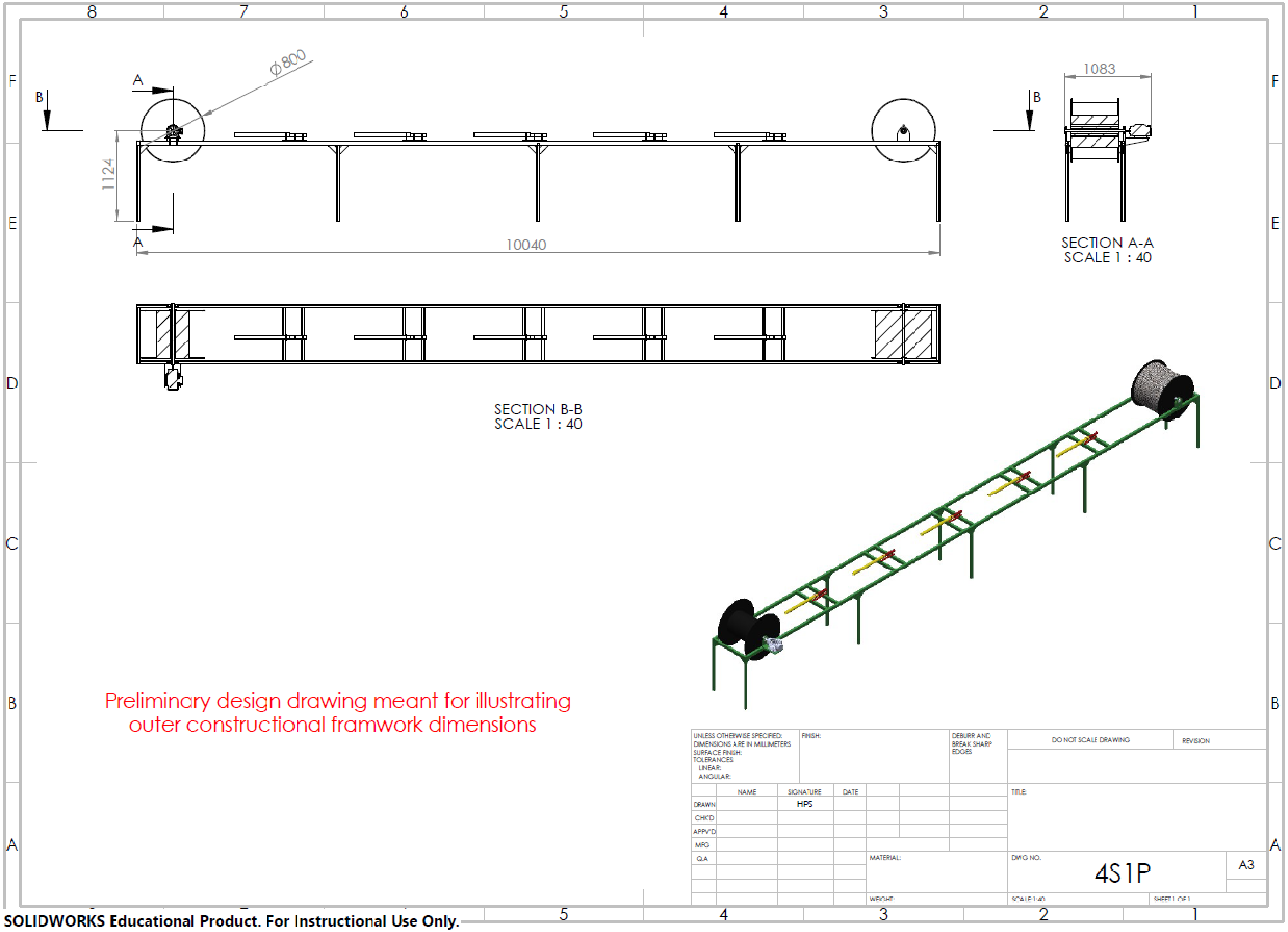

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Preliminary design drawing meant for illustrating
outer constructional framwork dimensions
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TOLERANCES:
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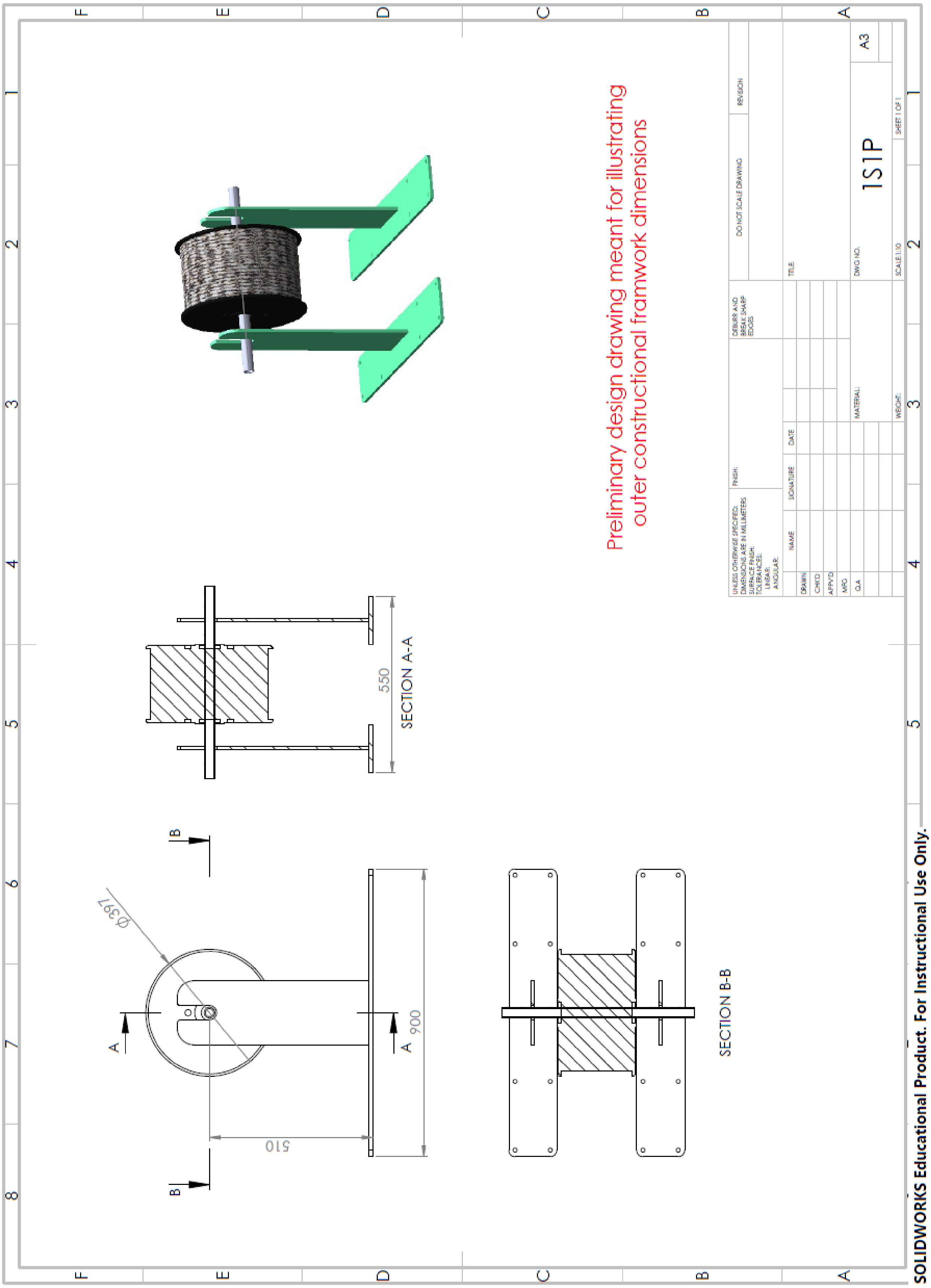
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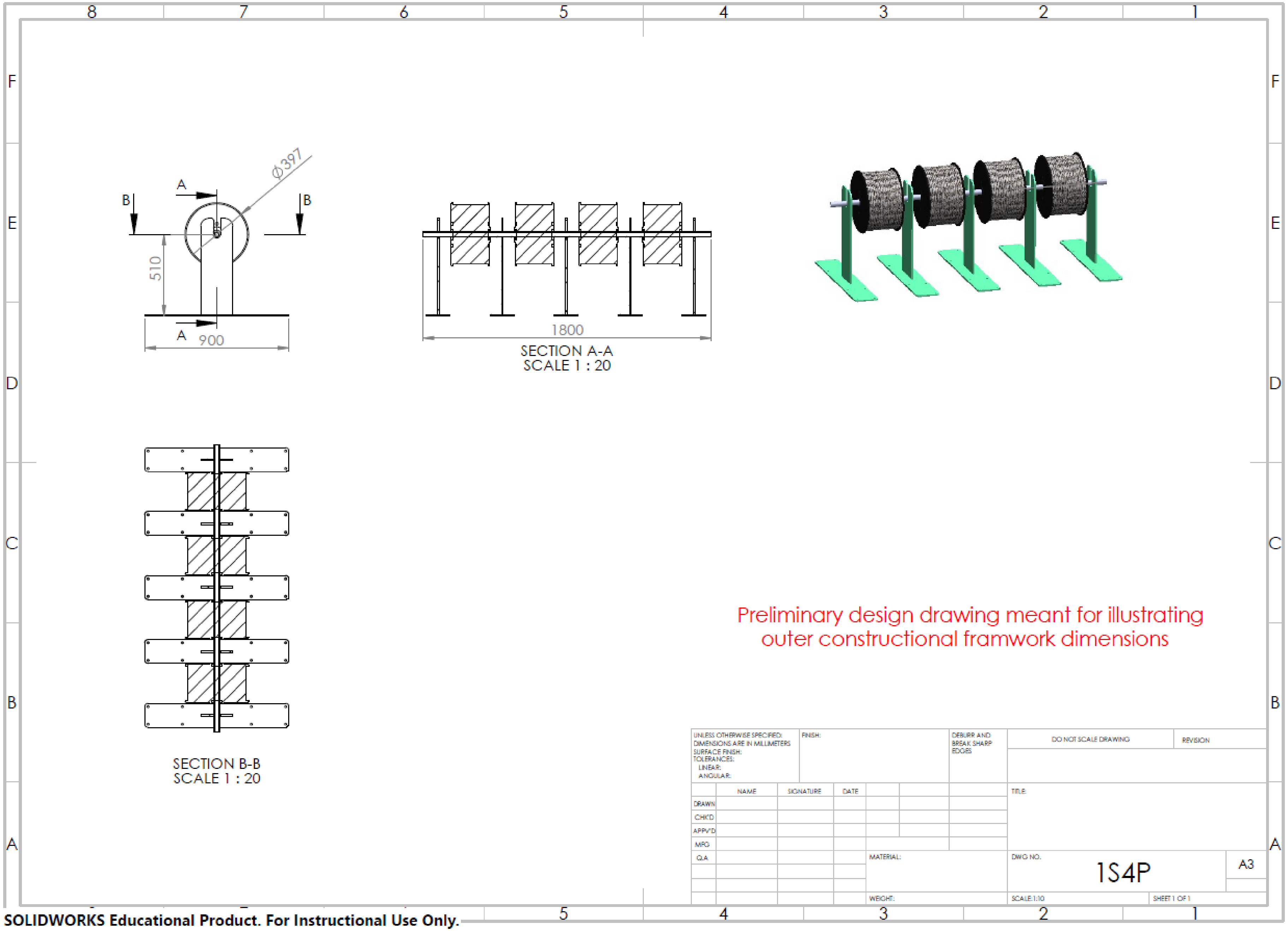

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Risk Analysis Matrix – Asphalt Seaweed Shuttle

	Likelihood	Rare	Unlikely	Moderate	Likely	Certain
	Description	The event may occur in exceptional circumstances.	The event could occur at some time.	The event will probably occur at some time.	The event will occur in most circumstances.	The event is expected to occur in all circumstances.
	Frequency	At least once during preparation and testing.	At least once during preparation and testing.	At least once during test.	Less than once per deployment.	At least once per deployment.
Consequence	**Level**	**1**	**2**	**3**	**4**	**5**
Negligible No injuries. Low financial loss.	**0**	0	0	0	0	0
Minor First-aid treatment. Moderate financial loss.	**1**	1	2	3	4	5
Serious Medical treatment required. High financial loss. Moderate environmental implications. Moderate loss of reputation. Moderate business interruption.	**2**	2	4	6	8	10
Major Excessive, multiple long term injuries. Major financial loss. High environmental implications. Major loss of reputation. Major business interruption.	**3**	3	6	9	12	15
Fatality Single death.	**4**	4	8	12	16	20
Multiple Fatalities Multiple deaths and serious long term injuries.	**5**	5	10	15	20	25

Risk Rating	Risk Priority	Description
0	N	**No Risk:** The costs to treat the risk are disproportionately high compared to the negligible consequences.
1 – 3	L	**Low Risk:** May require consideration in any future changes to the work area or processes, or can be fixed immediately.
4 – 6	M	**Moderate:** May require corrective action through planning and budgeting process.
8 – 12	H	**High:** Requires immediate corrective action.
15 – 25	E	**Extreme:** Requires immediate prohibition of the work process and immediate corrective action.

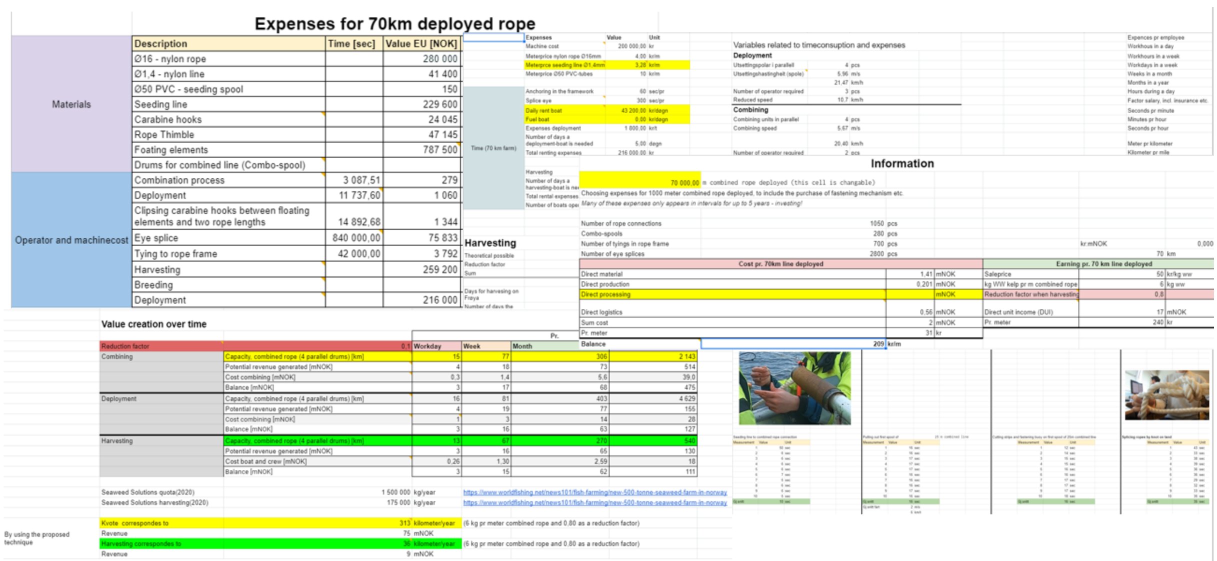
Number	Desciption	Consequence	Frequency	Total
01	Clamp fingers	1	3	5
02	Fall out of car during movement (max. 15km/h)	1	3	3
03	Crash with car on open parking lot (max 15km/h)	3	2	6
04	Drive over pedestrians	3	2	6
05	Fall over knife	3	2	6
06	Cut oneself with knife	2	3	6
07	Bang head	2	2	4
08	Clamped between deployed rope and car	3	3	9

Corrective action:
08) We had briefing before starting the test to ensure everyone knew on which signal the person in the back was ready for testing.

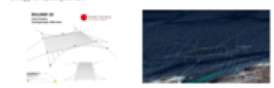
Figure 66: Risk analysis

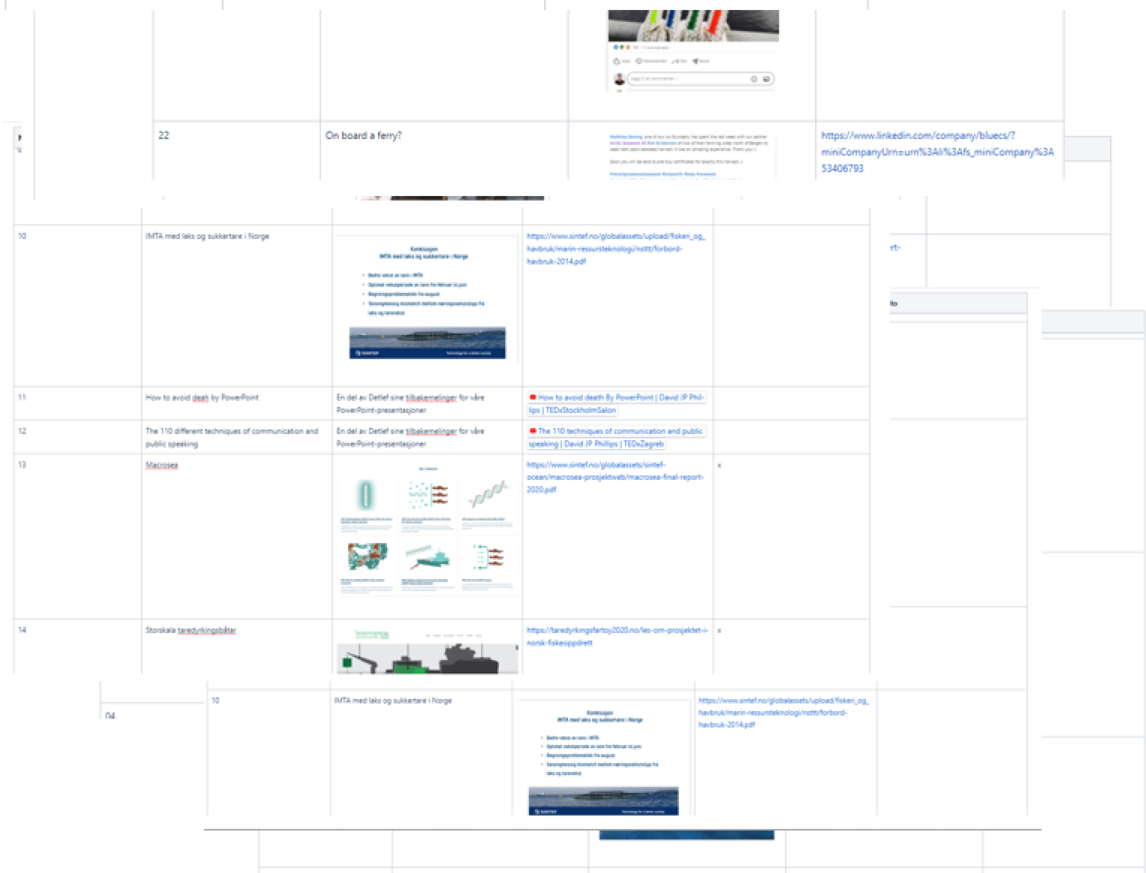
	Description	Value	Unit		
Combining	Work hours pr. day	7,5	hrs		
	Days pr. week	5	days		
	Production weeks pr. year	4	weeks		
	Combing rate	3	km/h		
	Total rope length	**450**	**km**		
Deployment	*Description*	*Value*	*Unit*		
	Work hours pr. day	7,5	hrs		
	Days pr. week	5	days		
	Production weeks pr. year	4	weeks		
	Combing rate	3	km/h		
	Total rope length	**450**	**km**		
Quota	*Description*	*Value*	*Unit*		
	Wet weight kilogram pr. m	6	wwkg/m		
	Reduction factor (loss)	0,7			
	SS quota (2020)	1500	tonnes		
	Corresponding rope length	**357**	**km**		
	Potential increased capacity, combining	**1,26**		26	%
	Potential increased capacity, deployment	**1,26**		26	%

Figure 67: Draft of potential rate



Background, market study, competitors, collaborators and brain food throughout the project is shared in the journal.

Nummer	Tittel	Info	Link
		0:50 Måte å legge kombinert line på spole	
34	Konkurentar	Har samarbeida med AMATEC 	https://www.vaerlandetfiskeredskap.no/ei-spanande-nring-1
35	Mal for bacheloroppgåve	Ein mal på engelsk for skriving av bacheloroppgåve.	https://www.umb.no/statisk/noragric/education/bach/Bachelor thesis guidelines.pdf
36	Havforskningsinstituttet	Mot en ny havnæring for tare?	https://www.hi.no/hi/nettrapporter/fisken-og-havet-2020-5
37	Potensiell kunde	Dei ser ut til å selje algenat som eit dyrefôr-produkt, blant anna	https://www.algea.com/index.php/Sustainability
38	Production	Lofoten based company	https://www.lofotenblueharvest.com/en/production
39	Production	Company using the glue-dip technique	https://www.tangoseaweed.no/blog/2018/2/8/kelp-seeding
40	LaTeX	Brukarvennlig mal for latex	https://www.uio.no/studier/emner/matnat/math/STK-MAT2011/v09/annet/forelesning-03feb2009.pdf
41	Multi Harvesting	Benefits of multi seasonal harvesting	Production method and cost of commercial-scale offshore cultivation of kelp in the Faroe Islands using multiple partial harvesting
42	SPOKe	Autonomous seaweed farming concept	Automation Concepts for Industrial-Scale Production of Seaweed



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