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Report

D5.4 State of the art

MACROSEA WP5

Morten Omholt Alver

Torfinn Solvang, Henrikke Dybvik

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AUTHOR(S)
Morten Omholt Alver
Torfinn Solvang, Henrikke Dybvik

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ABSTRACT

The objective of the MACROSEA project is to facilitate industrial scale cultivation of seaweed in Norway. To achieve efficient large scale cultivation, development of cultivation technology is an important component, and in Work Package 5 – *Seedling, Deployment and Harvest Technology* – the objective is to identify requirements and bottlenecks for industrial scale seedling production systems, and evaluate and develop concepts for deployment and harvest operations. In order to understand the limitations and potential of today's cultivation methods, an initial work has been undertaken to get an overview of the methods used by today's producers. The opinions of the producers on future challenges and bottlenecks have also been requested. This report summarizes the questions that were asked of the producers, and the answers received.

PREPARED BY
Morten Omholt Alver

SIGNATURE
Morten O. Alver

CHECKED BY
Aleksander Handå

SIGNATURE
Aleksander Handå

APPROVED BY
Gunvor Øie

SIGNATURE
Gunvor Øie

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Table of contents

APPENDICES

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1 Introduction

The objective of the MACROSEA project is to facilitate industrial scale cultivation of seaweed in Norway. To achieve efficient large scale cultivation, development of cultivation technology is an important component, and in Work Package 5 – *Seedling, Deployment and Harvest Technology* – the objective is to identify requirements and bottlenecks for industrial scale seedling production systems, and evaluate and develop concepts for deployment and harvest operations. In order to understand the limitations and potential of today's cultivation methods, an initial work has been undertaken to get an overview of the methods used by today's producers. The opinions of the producers on future challenges and bottlenecks have also been requested. This report summarizes the questions that were asked of the producers, and the answers received.

2 Literature survey

The biology and environmental interactions involved in seaweed cultivation are widely treated in the scientific literature. However, scientific publications covering cultivation technology for seaweed are few. Descriptions of production protocols, although production technology is not covered in detail, are given by Forbord et al. (2012) who describe seedling production and sea cultivation on long-lines, and provide data from a cultivation experiment in Mid-Norway. A book chapter covering sugar kelp production protocols in the book *Protocol Book on Macroalgae* is forthcoming (Forbord et al.; in press). Buck & Bucholz (2004) have presented a "ring carrier" cultivation system for open ocean macroalgae cultivation, which is shown to have high resistance to rough weather conditions while being easy to handle for farmers. Titlyanov & Titlyanova (2010) present an overview of the state of the art in global seaweed cultivation, including both intensive and extensive production methods. Ask & Azanza (2002) review cultivation status and production systems for eucheumatoid species, a group of red seaweeds. An overview for part of the Chinese seaweed industry is given by Su et al. (2017), who present large-scale hatchery production of the kelp *Saccharina japonica* in China, "including pre-treatment of parental plants, control of spore release, and control and adjustment of solar irradiance and temperature at different developmental stages of the plants as well as the nutrient supply regime over the entire course". Yang et. al. (2017) is another Chinese paper which describes a development of a mechanized harvesting machine, designed for the traditional floating raft seaweed farms.

3 Questionnaire sent to industry partners

Information was gathered from MACROSEA industry partners through an e-mail based questionnaire. The e-mail sent was formulated as follows:

Dear MACROSEA industry partners,

As you know, Work Package 5 in MACROSEA covers technology for seedling production, deployment and harvesting. The objectives of WP5 are as follows:

1. Identify requirements and bottlenecks for industrial scale seedling production systems
2. Evaluate and develop concepts for deployment
3. Evaluate and develop concepts for harvest operations

We want the results from WP5 to be as relevant and useful to you as possible. Therefore, our first step is to look at existing technology and methods used in the industry. As industry partners we ask you to contribute to this review by describing the methods and technology used in your production. You are of course not obliged to share confidential information or trade secrets, but any information you provide will help us determine the state of the art and form a foundation for our work in the project.

We would like to have the feedback from all partners within **March 10**. You can provide written feedback, or feedback through a meeting or phone call. If you want a meeting or phone call, please contact me to find a suitable time.

The following items describe more in detail what information we are looking for. Feel free to provide descriptions of your process and technology beyond these questions as well.

If your activities involve seedling production and seeding of substrate:

1. Describe the scale (annual production or batch size) of your system
2. Describe your seedling production system. If possible, provide pictures or drawings.
3. What types of instrumentation do you use to monitor water quality, density and quality of seedlings, or other parameters?
4. Describe the methods and technology used to seed substrates for deployment
5. Describe challenges and potential for improvement based on your experience

If your activities involve deployment of macroalgae:

1. Describe the scale of your deployments (e.g. annual produced biomass)
2. Describe your farming concept – dimensioning of farm, substrate type, ropes, mooring or other elements
3. Describe the methods, vessels and technology used in the deployment
4. If possible, provide pictures or drawings of your equipment
5. What are the methods and technology used to monitor the biomass through a production cycle?
6. Describe challenges and potential for improvement based on your experience

If your activities involve harvesting of macroalgae:

1. Describe the scale of your harvesting operations (e.g. annual biomass)
2. Describe your harvesting vessels. If possible, provide pictures or drawings.
3. Describe the methods and technology used for harvesting

4. Describe how you transport and deliver biomass for processing
5. Describe challenges and potential for improvement based on your experience

4 Responses

The questionnaire was sent to the MACROSEA industry partners:

- Austevoll Seaweed Farm (Austevoll, Hordaland)
- Biokraft (Skogn, Trøndelag)
- Folla Alger (Steigen, Nordland)
- Ocean Forest (Rongøy and Austevoll, Hordaland)
- Hortimare (Solund, Sogn og Fjordane)
- Seaweed Energy Solutions (Frøya, Trøndelag)
- Seaweed AS (Bulandet, Sogn og Fjordane)
- PE Reefs

In the following sections, the information received from all responding producers (Ocean Forest, Seaweed AS, Seaweed Energy Soluitions, Hortimare and PE Reefs) is shown, organized into information on *Seedling production*, *Deployment* and *Harvesting*. The responses have been edited for readability and adapted for the report format. Additionally, some information is given on producers not included in the survey.

4.1 Ocean Forest

4.1.1 Seedling production

Ocean Forest has so far bought sporophytes, and has no sporophyte production at present. Have experienced that the cost of pre seeded is a bit more than direct seeding. Ocean Forest believe there is a time-window where direct seeding works better, but do not have enough experience to estimate the timing and duration of this window. According to Ocean Forest's experience it is easier to control the amount and quality of seedlings when using pre seeding.

4.1.2 Deployment

Ocean Forest has two licenses of 150 tonnes each for "butare" and sugar kelp, and has in the 2015-2016 season tested various ways of seeding and growing kelp. A simple carrier rope where a thin rope seeded with sporophytes is spun around seems to be the most reliable. There has been a dialogue with SINTEF regarding the seaweed spinner developed at Sealab. The capacity of the spinner is too low and they want to make a larger version. A mechanical workshop has been contracted to develop a new version of the machine.

They use ordinary risers (Ø158 m) and traditional "bøyestrekk". No customized methods, vessels and technology are used in the deployment – they use ordinary work vessels from salmon farms.

The biomass is measured and weighed, no specific monitoring technology is used.

4.1.3 Harvesting

Ocean Forest sees the need for efficient harvesting and storage of the algae until it is to be packaged. At the moment the discussion addresses different solutions including floating stages, but they have not come far. There has been a dialogue with Plastfabrikken AS, who have made some initial drawings of a concept solution.

4.1.4 Main challenges

The primary challenges noted by Ocean Forest are:

- Rapid spinning of sporophytes onto carrier rope

-	Efficient harvesting technology

4.2 Seaweed AS

4.2.1 Seedling production

Seaweed AS uses material from Hortimare, both spools with seeded rope (pre seeding) and sporophytes (direct seeding) sprayed onto canvas. They have positive experience with the spinning process, seeing that it works very well and gives a proper amount of biomass. Seaweed AS have tested direct seeding and experienced very poor results (the cause of the poor results is not clear).

The substrate is seeded on land, placed in a boat and deployed manually.

4.2.2 Deployment

Two licenses for cultivation (150 tonnes each?). Sugar kelp and butare, grown for human consumption. The seaweed is grown on horizontal lines placed at 0.5 and 1 m depth (Figure 1). The horizontal lines are 100 m long, placed on 0.5 – 1 m depth.

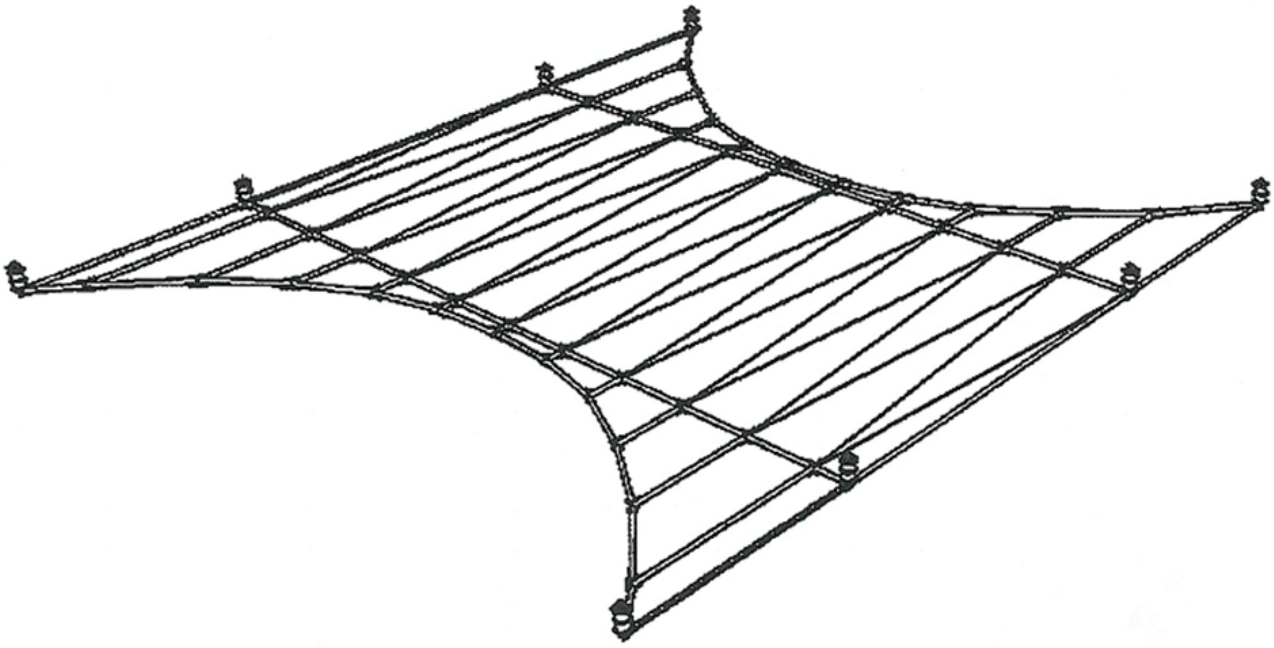

Figure 1: Sketch of Seaweed AS cultivation system

4.2.3 Harvesting

Seaweed AS has focus on development of harvesting equipment. Have done experiments with packaging for end users, but does not have strong focus on product development.

Currently using a fishing vessel and believes this is the way to go, mostly because of the mobility. Size and dependence on weather is also important when choosing or developing vessel. It needs to be easy to control and manoeuvrable. Considers using the same vessel for deployment and harvesting, only with a unit/module change which is relatively simple. Other processes that might be necessary to develop are cleaning of the rope and the ability to cut the tip of the kelp (difficult because they all have different lengths) because it might not be suited for food.

During the next year, they are focusing on harvesting and rinsing of the seaweed, and storage on board the fishing vessel. Possible solutions are transporting the kelp into a tank inside the vessel (similar to storage of fish), having the seaweed transported in a net kept outside the vessel below the surface, or having the seaweed transported into a net in bag. If the net is to be kept in the water, contamination and interactions with other boats or traffic need to be considered. Believes storage between harvest and processing is a crucial, thinks about direct freezing of the kelp. Inspiration might be drawn from line fishing and kelp trawlers. Believe it would be better to harvest under water because the seaweed quality degrades quickly once it is in contact with air. One possibility is to have a moon pool within the vessel (an opening in the centre of the boat hull allowing access to the water from the inside) and harvest the seaweed there. They have been in contact with Plastfabrikken AS, who are following up this idea.

4.3 Seaweed Energy Solutions AS

4.3.1 Seedling production

Seedling production system: Horizontal incubation in trays (1.2x2.4 m) and vertical incubation in algae bags (SINTEF style). Seed with spores or gametophytes. Flow through systems are used.

Monitoring of seedling production: Microscopy to monitor growth. Water source is UV and 1µm filtered deep water. Samples of intake water are taken every second week. Density of seeds either by Bürker chamber (spores) or by OD (gametophytes), in addition visual inspections of colour and microscopy are important. Visual inspection of seedling density and size before deployment.

Seeding substrates for deployment: SES has used direct seeding on ropes in hatchery in the Pilot, the only large-scale application so far. Hatchery size at this stage is not the limiting factor, and by seeding directly on the ropes that will be deployed in sea, the time consumption of sea operations, which is critical, can be limited. However, "vector seeding" (application of seeded strings on bigger culture substrate) is considered an option for future steps. This needs to be automated. Due to significantly lower string consumption, an automated “splicing” method would be preferable to rolling the string around a culture substrate (and much more versatile, as it could potentially be applied to more complex substrates (nets, sheets, etc.).

Main challenges: The "direct seeding on ropes in hatchery" method, although being by far the most practical for the relatively time-consuming manual deployment process in the present phase with volumes of several tens of tons wet weight per year, will be a limiting factor for hatchery efficiency. It also requires an early definition of all details of the deployment sequence, and thus leaves little room for adjustments and continuous improvements. Very useful would be a "seeded string injection machine" that unrolls pieces of seeded string, injects them into a thread of the culture rope every, say, 10-15 cm, and then cuts the string and pulls the next piece. The concept for such a machine exists at SES, however drawings and engineering need to be made and machine built. Further, "flash seeding" (similar to what At Sea call direct seeding) by immersion or other process has been tested at SES in the past with various results. A systematic approach to flash seeding techniques would be another high added value for the industry.

4.3.2 Deployment

Production scale is approximately 50-100 tonnes per year.

Farming concept: Long line system. Submersed longlines of 200 m length and 15 m spacing carrying vertical or horizontal seeded substrate.

Methods, vessels and technology: 7.5 m aluminium vessel (leisure fishing type) with purpose-made apparatus in stern for unrolling continuously the seeded rope. Important to limit vessel size according to available substrate batches (costs). Methods need to be reviewed once larger deployment volumes are envisaged (weather windows).

Monitoring of biomass: Deployments and harvest windows have been identified by continuous deployment tests every second month for 4 years. Length, wet weight and state of fouling has been monitored for 4 years every 2-4 week through the grow out period, and every 8 week in the rest of the year.

Main challenges: Weather windows for deployment period. Up to now, deployment window has primarily been January-February. Weather and access to site are rather unpredictable in this period. More stable (larger) deployment vessel and automated deployment process ("no hands on ropes") are essential for up-scaling. Process is still manual and time-consuming. Fast attachment mechanism (probably knotless) of substrate ropes to LLs is vital. Clip prototypes have been developed and partly tested at SES and showed promising results with respect to growth period; however costs are still too high for large-scale production and automation process is not yet developed.

4.3.3 Harvesting

Scale of approx. 50-100 tons during May/June (total harvest window of about 40 days). Near-future up-scaling towards 500 tons depending on market pull and processing methods available ("proven product").

Harvesting vessels: 12 m work platform/vessel.

Methods and technology: Lifting of longline out of water with crane. Manual removal of biomass from substrate.

Transport and delivery: Interim storage in nets in seawater. Then towing or on-deck transport to dock.

Main challenges: In the 2014-2015 season, a harvest volume of 5 tons/day with one vessel and manual process was demonstrated. However, efficiency is somewhat limited with manual processes, and it is tiresome work. Mechanical apparatus is essential for larger volumes.

Harvesting is weather dependent and with a short overall time window for harvesting, the number of days at sea for harvesting is limited. Possibility for operating in rougher conditions is important in the future.

Could be realised relatively straightforward, if the cultivation system is designed accordingly. Main issue will be temporary (on-site or in-water) storage of harvested biomass for buffering between biomass harvesting and on-land processing. Preprocessing on vessel appears a valid option for future up-scaling visions.

4.4 Hortimare

Hortimare is not a seaweed cultivation company, but provides seedlings, systems and services to other companies.

4.4.1 Seedling production

Hortimare supplies sugar kelp, oarweed, fingerkelp, winged kelp, dabberlocks, sea lettuce and dulse.
Two types of seeding systems are provided:

- Twine seeding, seeded rope spun around carrier rope. The seedlings are applied to the rope, followed by cultivation in laboratory for 1-1,5 months. This lead-time is zero with direct seeding. The benefit from this process is slightly higher yield of biomass, because the cultivation starts earlier. However, the difference is reduced over time, and, according to Hortimare, the trade-off between lead-time and yield might favour direct seeing when it comes to cost and productivity.

- Direct seeding (Figure 2), seedlings "glued" to the substrate using HSA, a specially developed adhesive for this purpose. Seeding density and uniformity is improved (no twists and patches) and application costs are lower. The yield is equal to or higher than the traditional twine system. Direct seeding is done at an earlier stage than twine seeding, thereby extending the sea phase of cultivation. The seeding consists of a bath of seedling, which is then presses into the rope. The rope is made of a synthetic material and is has a certain structure. This process is easy to scale. It might be inconvenient that you cannot seed earlier (the seeded rope can be stored for a small amount of time, maximum a week). Since a glue is used, according to Hortimare the success rate is 100% for the outgrowth of sporophytes (tested over 4 years already).

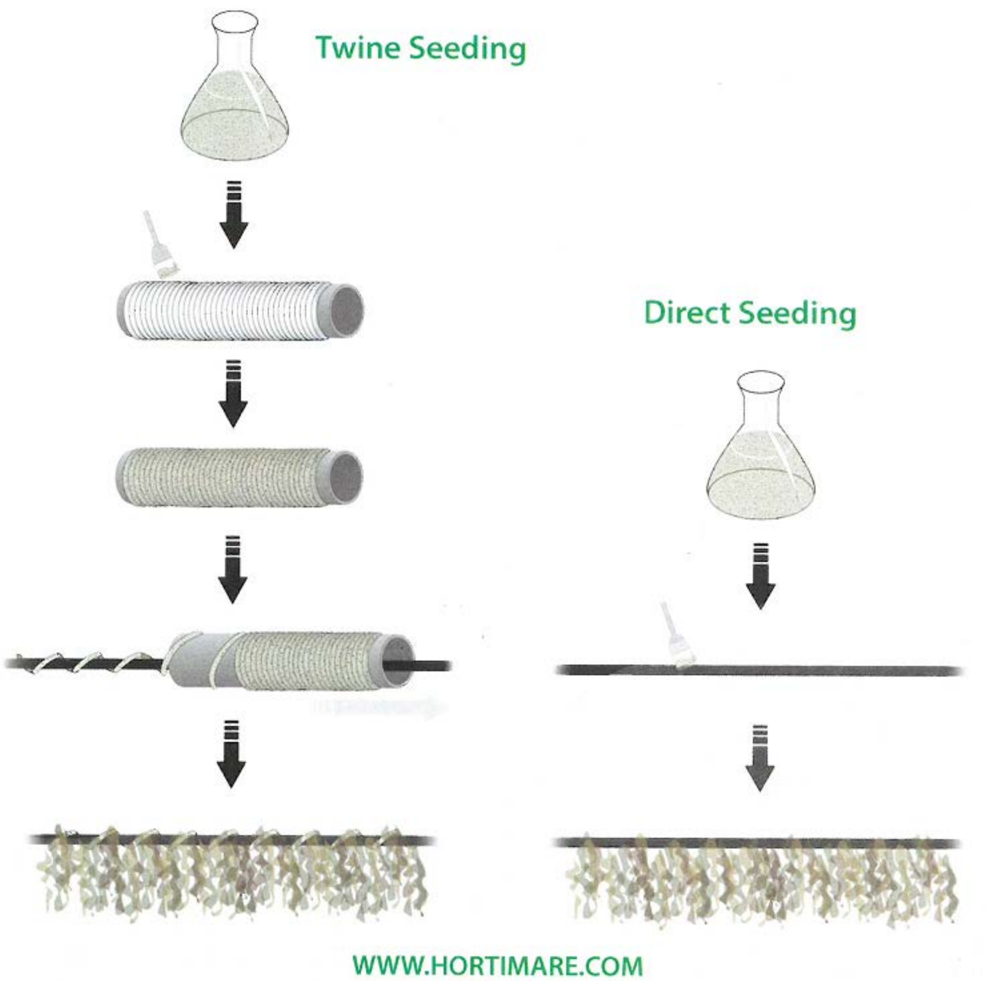

Figure 2: Hortimare seeding system. Figure from Hortimare flyer.

4.4.2 Harvesting

Hortimare develops harvesting equipment for rope-based cultivation.

4.5 PE Reefs

PE Reefs do not cultivate seaweed yet, but have developed a cultivation concept based on polyethylene pipes. They are currently patenting a cultivation facility and financing a prototype to be placed at SINTEFs cultivation site at Frøya. PE Reefs believe direct seeding is the way to go and it might be a challenge to reduce the cost price. They seek to establish a good collaboration with Hortimare in order to achieve this. With the PE Reefs concept, it is not possible to twine the string around a carrier rope. They believe it is possible to industrialize the processes around their cultivation concept, and make if more efficient compared to today.

Main questions that PE Reefs are interested in from MACROSEA:

- Is it possible to grow seaweed spores directly on plastic?
- Growing spores on ropes – what pattern is the most efficient?
- Growing spores on textiles – what pattern is the most efficient?

PE Reefs also produce and assemble artificial reefs using PE pipes. By installing reefs they aim to reduce the environmental effect of human interference along the coast, increase biodiversity at the seabed, and improve the local water quality. Reefs are assembled on land, towed to locations using a small tugboat, and submerged there.

4.6 Other producers

The following sections give some information on producers not included in the questionnaire.

4.6.1 Cultivation in China

Cultivation is traditionally done on ropes. Sporophytes are artificially grown. Seeding is carried out in hatcheries. Deployment and harvesting is done manually, requiring much manpower and small row-boats. Some species require daily cleaning; this is executed manually with spray guns.

A recent publication (Yang et. al., 2017) describes a development of a mechanized harvesting machine, designed for the traditional floating raft seaweed farms (Figure 3). This machine uses a hydraulic locomotion module to pull itself along two of the longitudinal floating raft ropes at a time, with the result that the grown kelp ropes (in between the raft ropes) are taken on board, processed and the kelp is stored.

The machine was built and tested in 2016, and gave a significant increase in efficiency. The kelp ropes are still detached from the longitudinal raft ropes by hand, and the machine does not offer any automation of removing the kelp from the kelp ropes. However, the first point is subject to further development for future work.

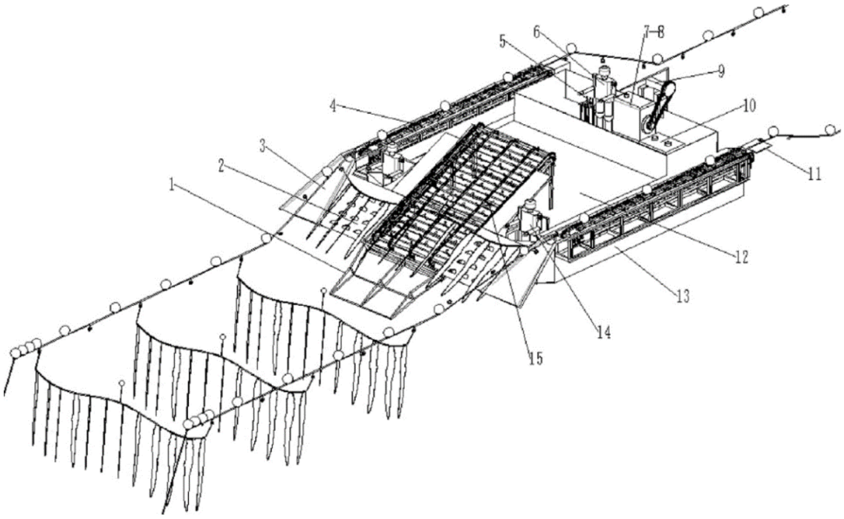

Figure 3: Mechanized harvesting machine. From Yang et.al., 2016

Another recent publication focuses on the demand for a steady supply of sporelings in the giant kelp farming industry (Su et. al., 2017), and seeks to shed light on the most critical aspects of the hatchery process. This work defines the most important factors for the final quality of sporelings as: 1. Plantlet density on the string, 2. Control of irradiance throughout the entire course, and 3. Nutrient supplements.

Below (Figure 4) is a schematic of the proposed water recirculation system.

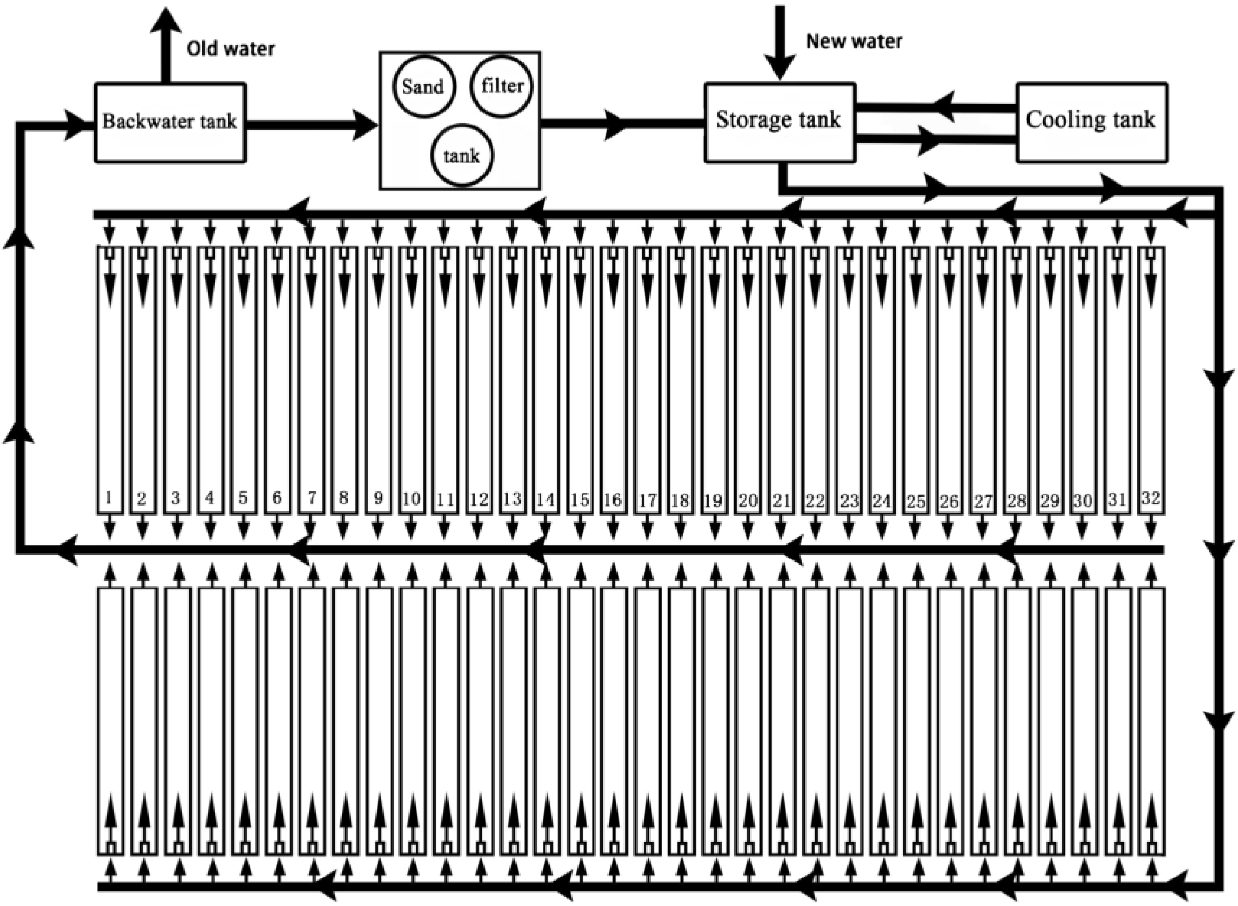

Figure 4. Recirculating water schematic, seaweed hatchery (From Su et al., 2017)

4.6.2 Ocean Approved

Cultivation in Maine using open-ocean kelp farms. They have prepared a manual for this, which can be downloaded from http://www.oceanapproved.com/sustainability/.

5 Summary of main challenge

The following items are the main challenges outlined by the responders:

- Rapid spinning of sporophytes onto carrier rope (Ocean Forest)
- Efficient harvesting technology (Ocean Forest)
- The "direct seeding on ropes in hatchery" method will be a limiting factor for hatchery efficiency (SES)
- Weather windows for deployment period. Faster, more automated process is needed (SES)
- Mechanical apparatus for more rapid harvesting is needed (SES)
- Possibility for harvesting operations in rougher conditions is important to increase time available for harvesting (SES)
- Storage between harvest and processing (Ocean Forest and Seaweed AS)

These items provide valuable insight into the challenges faced by the industry. As some of the challenges are related to the various methods of seeding substrate, it might be useful to establish a joint nomenclature on the different seeding methods in order to ease communication.

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