MacroFuelsProject

POLICYBRIEF

The Environmental Impacts of Large-Scale Seaweed Cultivation

Findings and recommendations from the MacroFuels Horizon 2020 research and innovation project (www.macrofuels.eu)

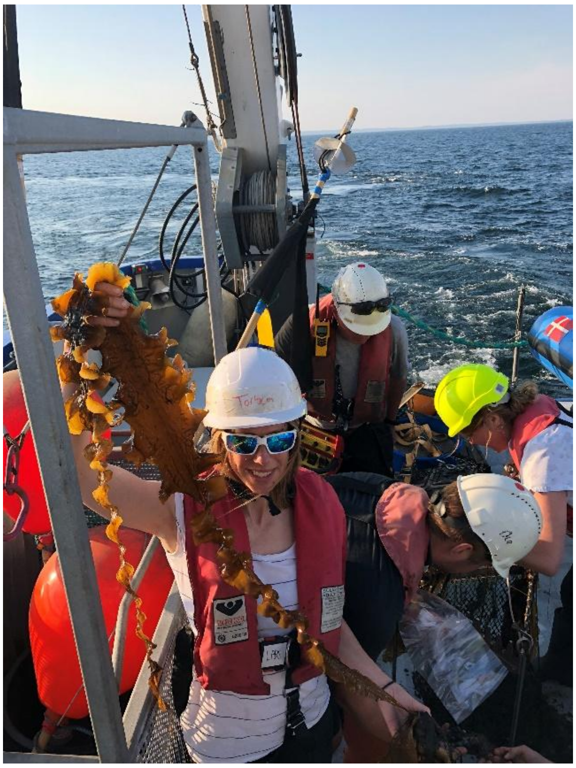
Key Messages

1. Environmental effects of seaweed cultivation are **site and scale dependent**
2. Seaweed production may contribute to **climate change mitigation**
3. Nutrient uptake of seaweed production may **counteract eutrophication**
4. **Site selection and management** are crucial for optimising ecosystem services and minimizing risks
5. **Best practice guidelines** need to be defined
6. **Thresholds of acceptable impacts** need to be defined
7. **Impacts on biodiversity and biosecurity** of large-scale seaweed cultivation needs further investigations, and calls for exercising the precautionary approach

European seaweed cultivation at large scale

Seaweed cultivation if properly managed can provide ecosystem services whilst developing marine resources currently underexploited throughout Europe.

Seaweed for fuels, feed, food and value added products is advancing in Europe. Complementing or substituting land-based crops with seaweeds – in particular for fuels and feed, calls for large-scale* production. Cultivation of seaweeds requires space at sea, but no land-use, no freshwater, no fertilizer and no pesticides. European North Atlantic waters are well suited for cultivation of large brown seaweeds (kelps). Kelps can be seeded onto cultivation substrates, such as ropes or nets, and the kelp grows in the sea from autumn to early summer. Seaweed cultivation is a young technology in Europe, and the processes and materials involved are undergoing rapid development towards higher product yields and quality, and lower costs and impact. Deploying seaweed cultivation systems and cultivating seaweeds in the sea has impact on the local marine environment. With optimal site selection and good management practice, large-scale seaweed cultivation has the potential to deliver important ecosystem services such as climate change mitigation, bioremediation of eutrophication and protection of coastal areas. Potential risks include loss of materials, spreading of non-native species, diseases and pest, and genetic depression of local seaweed populations. The nature and scale of impacts and risks will depend on the cultivation site selected and site management.



*Large-scale seaweed cultivation is presently defined as more than 50 longlines of each 200 m (Marine Scotland, 2017).

Environmental impacts and risks

Lately, many positive environmental impacts of seaweed have been discussed in the general media and by seaweed enthusiasts. While many effects can be verified and quantified, for example the ability of seaweed to capture CO_2 and excess nutrients while growing without any fresh water, arable land or fertilizer, the full environmental impacts of a large-scale seaweed production site are still largely unknown. MacroFuels collected and evaluated environmental data from the project's seaweed test farms, aiming to contribute to the improved understanding of the complex environmental interactions of large-scale seaweed cultivation (see Fig 1).

1. CO_2 uptake – climate change mitigation

Like plants on land, seaweeds live through photosynthesis, using sunlight to convert CO_2 into hydrocarbons (sugars) for growth. The sugars can be used to produce climate-neutral fuels for substituting fossil fuels. The CO_2 uptake of seaweeds is equivalent to approximately 1.3 ton of CO_2 per ton of seaweed dry matter. Only a minor fraction of the CO_2 taken up by seaweeds is sequestered. Two other beneficial consequences of the seaweed photosynthesis is the production of oxygen, which is needed by marine animals and counteracts ocean de-oxygenation, and increase of sea water pH, which counteracts ocean acidification. Seaweeds however also emit other climate active gasses such as halocarbons, dimethylsulphide (DMS) and nitrous oxide. More research is needed to document the scale and consequences.

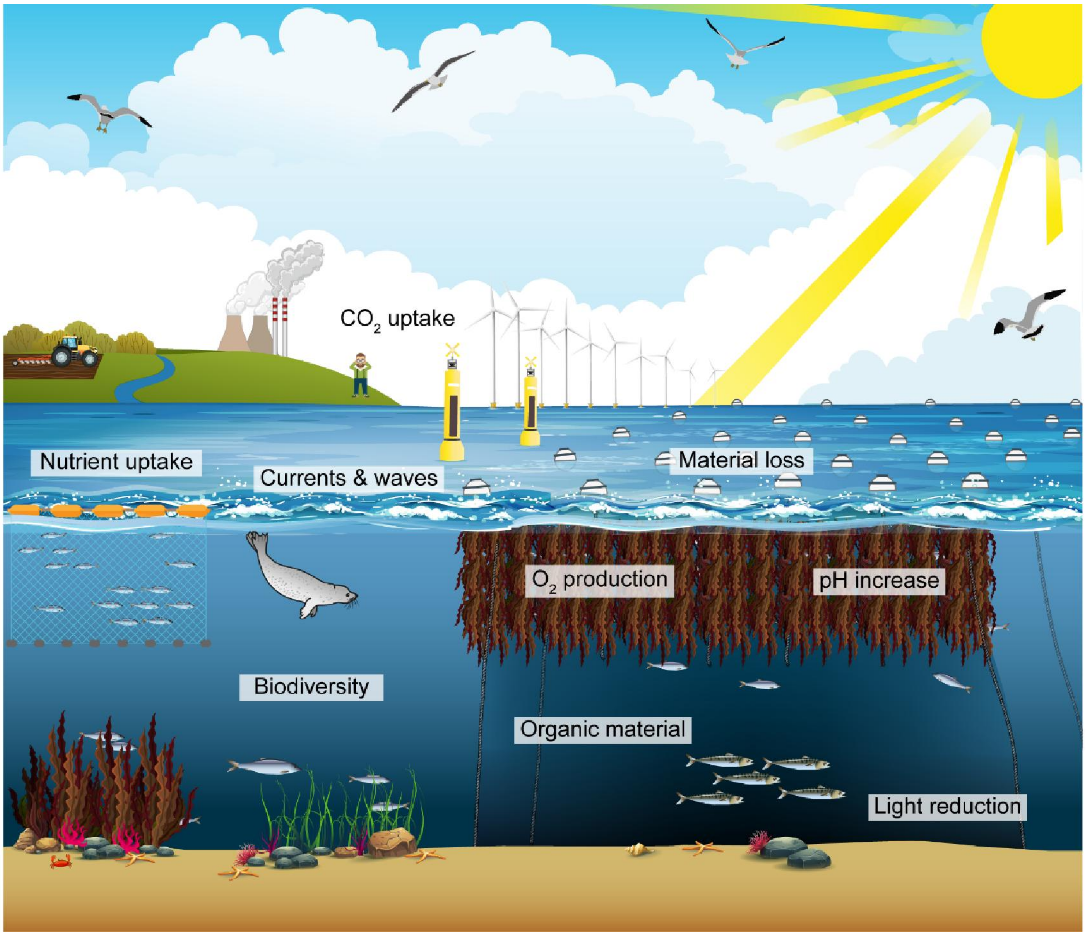


Fig 1 The complex environmental interactions of a large-scale seaweed farm

2. Nutrient uptake – counteracting eutrophication

Seaweeds need nutrients to grow, and efficiently take up nitrogen and phosphorus from the surrounding sea water. When harvesting the seaweeds, nutrients are removed from the marine system and made available for the bio-economical system on land (5-60 kg N per ton of seaweed dry matter). In most European coastal waters, nutrient emissions from human activities on land and aquaculture lead to eutrophication and reduced marine environmental quality. The EU Water Framework Directive demands accelerating the recovery of marine ecosystems from eutrophication. In eutrophic areas, seaweed cultivation could counterbalance the anthropogenic inputs of nutrients. In nutrient-poor marine areas however, competition for nutrients may limit seaweed productivity whilst having a negative impact on natural marine ecosystems. Site selection based on coupled hydrological-ecological modelling is needed to select the best sites for growing seaweed and offer ecosystem services.

3. Biodiversity

Introducing a seaweed cultivation system into the marine environment will increase the habitat complexity. The cultivation structure itself, as well as the seaweeds when growing, will provide feed, shelter and substrate for mobile and sessile marine organisms, increasing the local biodiversity. However, also "unwanted" species – non-native species, diseases and parasites – may use the cultivation systems as stepping stones for further dispersal. Intensive cultivation of a seaweed monocrop may in itself contribute to spreading of seaweed diseases and pests also to natural seaweed populations. Regarding genetic diversity, caution should be taken not to introduce and cultivate non-local cultivars, as spreading of genes to local populations cannot at present be avoided, and may reduce fitness of the local ecotypes. The industry to date has adopted precautionary practices that mitigate the above risks. Regulators should carefully consider the benefits of seaweed aquaculture and where possible incentivise projects that use cultivation systems and management practices to produce quantifiable benefits to local biodiversity and ecosystem services. This approach also has a vast potential in synergy with other marine activities (e.g. Integrated Multitrophic Aquaculture Approach, multi-use energy/biomass platforms).

4. Reduction of light to the seafloor

A "hanging seaweed forest" in the surface waters will absorb a fraction of the incoming light, and hence reduce the input of light to the sea floor for natural populations of seagrass, seaweeds and benthic microalgae. The impact will depend on the scale and density of the cultivation. Good site selection as well as placing of cultivation areas beyond the depth limits of natural benthic vegetation will minimize negative impact.

5. Loss of synthetic materials

Cultivation materials are typically produced from durable synthetic materials such as nylon and polypropylene. Loss of material is difficult to fully prevent, and may cause damage to maritime activities or to marine animals, due to entangling or consumption. Standards and regulations for site management, as for other aquaculture activities, will minimize the risk.

6. Loss of organic material

During growth, the seaweeds will naturally loose dissolved and particulate organic material to the environment. Some of this will stimulate the production of the local food web in the water column and in the sediment beneath the seaweed, and some may be buried in the seabed. If larger amounts of organic material are accumulated in depositional areas, local oxygen deficiency and impoverishment of the benthic biodiversity may occur. Site selection and site management will contribute to minimizing risks of negative impact.

7. Local current and wave patterns

Seaweed cultivation structures will influence the local hydrology (current patterns and wave action). This may affect the water exchange inside the cultivation area, and with this the access of the seaweeds to nutrients, the local patterns of sediment transport, the coastline, as well as the structure and productivity of local marine food webs. Site selection based on hydrological modelling will contribute to minimizing risks of negative impact.

- ✓ Uptake of CO_2 – climate change mitigation
- ✓ Production of oxygen – counteracting ocean de-oxygenation
- ✓ Local increase of pH – counteracting ocean acidification
- ✓ Uptake of nutrients – counteracting eutrophication
- ✓ Increase of species diversity
- – Changing local patterns of currents and waves
- – Increased sedimentation of organic material
- – Reduction of light to the seafloor
- × Risks of spreading of non-native/harmful species
- × Emissions of other greenhouse gasses
- × Loss of synthetic material

Environmental Risk Mitigation and Monitoring Needs

1. Definition of acceptable change

Seaweed cultivation at large-scale will alter many of the physical, biological, chemical characteristics of the environment. With proper site selection, many of these changes could be considered positive. However, as with other types of aquaculture there are risks of negative impacts. Authorities must define the thresholds for acceptable impact to ensure the carrying capacity of the environments suitable for cultivation are not exceeded and natural resources are managed effectively.

2. Site selection

Impacts on the local marine environment of large-scale seaweed cultivation will depend on the local conditions of geology, hydrology and ecology. Development of systematic site selection tools based on hydrological and ecological modelling will be crucial to optimize production and ecosystem services, in order to benefit from positive impacts and minimize negative impacts.

3. Best cultivation practice

Standards and regulations needs to be developed for a 'Best Cultivation Practice' for establishing and operating seaweed cultivation systems. Standards and regulations should include: Site selection, baseline surveys, selection of structure and materials, site management, monitoring practice, education. Monitoring programs should be customized to the scale of cultivation and avoid the costly collection of "data-rich, information-poor" (DRIP) data, while still securing documentation of positive and negative environmental change.

4. Biosecurity programs

The largest potential risk on the local marine environment is the spreading of non-native or harmful species such as seaweed diseases and pests to natural seaweed populations, or the introduction and spreading of genes from non-local cultivars that outperform local genes in the short run, but in the long run cause genetic depression and reduced fitness of local cultivars. Baseline knowledge of local species and genetic diversity needs to be established, including prevalence of non-native species, seaweed diseases and pests. Development of biosecurity programs including rapid diagnostic tools, and quarantine procedures must be included in future standards and regulations.

- ✓ Thresholds for acceptable change
- ✓ Site selection and site selection tools
- ✓ Best cultivation practice (education, standards for material selection, maintenance, timing of processes)
- ✓ Biosecurity: No cultivation of non-native species, only cultivation of local ecotypes

Knowledge gaps

- ✗ Impact dependency on site and scale
- ✗ Validated Marine Strategy Framework Directive indicators for assessing environmental status in cultivated seaweed systems, including biodiversity at the levels of ecosystems, species and genes
- ✗ Physical changes to coastal hydrography
- ✗ Local, regional and global changes to environmental chemistry, including seaweed emissions of greenhouse gasses
- ✗ Biosecurity planning for seaweed, i.e. seaweed diseases and pest – prevalence, diagnostic tools, quarantine procedures

Recommendations for further reading:

Campbell I, Macleod A, Sahlmann C, Neves L, Funderud J, Øverland M, Hughes AD, Stanley M (2019) **The environmental risks associated with the development of seaweed farming in Europe - Prioritizing key knowledge gaps**. Frontiers in Marine Science 6 (107). doi:10.3389/fmars.2019.00107

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Cottier-Cook E, Nagabhatla N, Badis Y, Campbell ML, Chopin T, Dai W, Fang J, He P, Hewitt CL, Kim GH, Huo Y, Jiang Z, Kema G, Li Y, Liu F, Liu H, Liu Y, Lu Q, Luo Q, Mao Y, Msuya FE, Rebours C, Shen H, Stentiford GD, Yarish C, Wu H, Yang X, Zhang J, Zhou Y, Gachon MM (2016) **Safeguarding the future of the global seaweed aquaculture industry**. Institute for Water, Environment and Health

POLICY RECOMMENDATIONS

1. To establish consent for large-scale cultivation projects, authorities need to implement ‘acceptable’ thresholds of environmental change
2. Develop and test coupled hydrological/ecological modelling as site selection tools for predicting yields and impacts
3. Establish standards for best cultivation practice, including baseline surveys (BACI), monitoring guidelines, material standards, education
4. Establish large-scale test farms in relevant environments, possibly as part of multi-use platforms
5. Locate future cultivation sites beyond depth limits of natural benthic vegetation
6. Protect local biodiversity by cultivating only native species and local genetic cultivars (**or** apply precautionary approach prior to allowing cultivation of non-native species and non-local cultivars)
7. Develop and validate indicators for evaluating impact on biodiversity at the levels of ecosystems, species and genes
8. Establish knowledge bases for local genetic variation of crop species and prevalence of seaweed diseases and pests
9. Develop and test Marine Strategy Framework Directive indicators for use in evaluating effects of seaweed cultivation om the marine environment

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Horizon 2020
European Union Funding
for Research & Innovation

This policy brief is part of the MacroFuels project. This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 654010.

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Duration January 2016 – December 2019

Budget EU Contribution: 5 999 892,50 €

Website at: All MacroFuels Policy Briefs, fact sheets and other publications are available https://www.macrofuels.eu/results-publications.