Growing Macroalgae Sustainably in the Baltic Sea
August 2021

Output 4.3.2

Synthesis Report

Benefits, risks and opportunities of macroalgae cultivation, harvesting and use at local, regional, national and transnational level

Foreword

Macroalgae production is an upcoming sector for growing biomass for producing food, consumables such as plastics and energy without competing for arable land, depleting fresh water and using non-renewable fertiliser. However, the sector is still in its infancy in the Baltic Sea Region and there is a lack of in-depth and wide-spread knowledge on the potential benefits of macroalgae production. To deal with this challenge, GRASS aims to raise awareness and build capacity on macroalgae cultivation, harvesting and use among public authorities and other relevant stakeholders across the region. Public authorities, ministries, planning regions and counties play a crucial role in promoting macroalgae as they are the main legislative bodies that also control much of national and regional funding.

The aim of Group of Activities (GoA) 4.3 "*Training material and capacity building activities for public authorities and practitioners*" is to build capacities of public authorities in the BSR to understand sustainable macroalgae cultivation, harvesting and use. Subtask 4.3.2 is this synthesis report, analysing and summarising the benefits, risks and opportunities at a regional, national and at transnational level of the BSR of macroalgae cultivation, harvesting, and use, encompassing environmental, ecological, regulatory and socio-economic aspects (input from GoA2.3, 3.1, 3.4, 4.1), including future recommendations for unlocking the potential of macroalgae.

Contents

2. 1 Assessing the PanBaltic potential of macroalgae cultivation and harvesting of wild stocks

Sustainable cultivation and harvest of macroalgae plays a key role in meeting the goals of blue growth initiatives in the coming years as maritime activities are expected to increase. To secure space for macroalgae cultivation, spatial planners need to know which environmental variables drive plant production as well as where productive areas are located. First, we pooled together all available data on environmental proxies and algal production to quantify relationships between macroalgal production and the environment as well as to predict macroalgae production at the Baltic Sea scale. Second, we built a similar model for macroalgal beach-cast and predicted the potential beach-cast production at the Baltic Sea scale. The resulting maps are useful for maritime spatial planning because they enable to detect the most suitable areas for macroalgae farming and/or beach-cast harvesting. From the range of suitable sites, it is then possible to detect areas that allow long term cultivation actions while considering trade-offs and avoid conflict with existing industries (e.g. fisheries, shipping routes etc). Information is accessible for everyone through the user-friendly ODSS online platform at http://www.sea.ee/bbg-odss/Map/MapMain. This tool guides public authorities interested in setting up, investing in or funding a farm in their region to private actors who want to get involved in the macroalgae business.

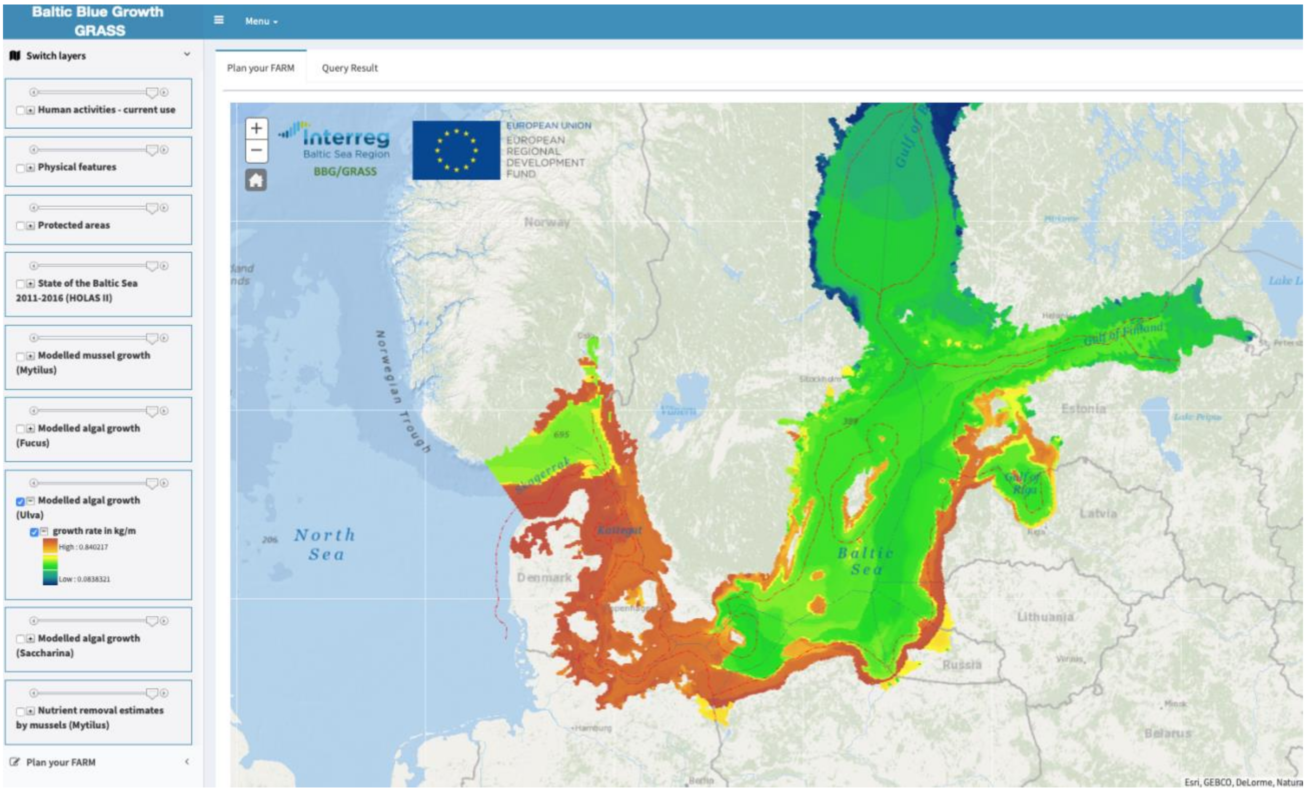

Figure 1: Screenshot of the Operational Decision Support Tool (ODSS)

The modelling of macroalgal and beach cast production potential has shown that macroalgae can be successfully farmed and harvested in much of the Baltic Sea when cultivation methods are adapted to the local conditions. With this activity we aim to close the environmental gap for macroalgae production. The ODSS tool that will help us to fulfil this goal by linking maps of the suitable sites for macroalgal cultivation and beach cast harvest with important environmental variables, state of the Baltic Sea and different human uses. The outputs will mainly be used by regional and national public authorities such as environmental and planning agencies. Other target groups are practitioners, research institutes and NGOs in the field of sustainable blue growth.

2.2 Manual on the efficient production methods of macroalgae farming in the Baltic Sea region

This report aims at highlighting the potential of macroalgae production in The Baltic Sea region. Three different production tracks; macroalgae cultivation, wild harvest of macroalgae and beachcast collection, were examined through a survey among the project partners within the "GRASS initiative", together with a literature study.

Seven potential production macroalgae species were identified for cultivation in the region. Cultivation is already ongoing in the Western Baltic Sea region on the Swedish west coast where cultivations of *Saccharina latissima, Laminaria digitata* and *Ulva sp*. are established. Land-based and small-scale coastal cultivations exist in the Baltic Sea region but with limited production because of low salinity, which inhibits high production of true marine species such as *Saccharina latissima*. *Furcellaria lumbricalis* is the only macroalgae species used in the region for wild harvest. In Estonia, an unattached form of the species is harvested each year in a limited amount. Four beach-cast projects were reported within GRASS (Latvia (2), Russia and Sweden), but small-scale projects of beach-cast collection occur in several parts of the region.

Figure 2: Fucus vesiculosus courtesy of Paul Levesley

Production challenges identified by the project partners include demanding environmental conditions, legislation obstacles, lack of knowhow and high labour costs. To overcome these challenges, we suggest that more focus and effort is put on research and development of production systems in the Baltic Sea. The precautionary principle must be the leading star in harvesting of Furcellaria lumbricalis, and sustainability aspects must also be considered for beachcast harvest in the region. To accommodate growth of sustainable macroalgae production systems for cultivation, harvesting and collection, we need knowledge transfer and build capacity to support the development of technology, legislation and policies in this area.

Sustainable Paths Forward

Potential pathways towards establishing a sustainable macroalgae industry in the Baltic Sea calls for addressing and overcoming several production-oriented challenges. An interdisciplinary approach combining environmental, technological and social/economic aspects of the challenges is crucial. It can be illustrated by a potential chain effect of events starting with building up knowledge of environmental effects from macroalgae production (cultivation, harvesting and collection). Such knowledge could serve as sustainability guidance for policy makers; and thus, simplify permit processes for macroalgae production. A more straightforward permit process could, in turn, secure or expand economic subsidies and increase investments in technological development, and other critical challenges. Discovering connections between different production challenges - including environmental, social, economic and technical aspects - could provide momentum for the development of macroalgae production in the Baltic Sea Region. The following tangible steps are recommended:

Key Messages and Recommendations

- For the Western Baltic Sea Region we recommend further development and streamlining of the relatively mature production technology for cultivation of *Saccharina latissima, Laminaria digitata* and *Ulva sp*. which are the only commercially off-shore cultivated species in the area today.
- There is an urgent need for more research and knowledge building about life- cycle, cultivation techniques, and product value chains for alternative species for open sea cultivations in the region, such as *Furcellaria lumbricalis*, *Fucus vesiculosus*. *Ulva sp*., *Chondra filum*, etc. This is specifically important for the Baltic Sea (Eastern Baltic Sea Region) since species with mature cultivation techniques and infrastructure found in other areas are lacking in the Baltic Sea. “New” production systems must therefore be developed before establishment is possible in the region.
- Land-based systems are available or under development already today for several species in the region such as *Fucus vesiculosus, Ulva sp., Saccharina latissima*. But infrastructure, technology and cost efficiency need to be improved for these systems to be commercially interesting. Land-based systems are advantageous by being less region-specific and by producing macroalgae biomass of high quality. Wild harvest of Furcellaria lumbricalis needs systemic analysis of environmental effects to assure that sustainable methods are applied. Research on cultivation techniques for *Furcellaria* aquaculture should also be promoted.
- The management systems for beachcast in the Baltic Sea Region are formed locally but the challenges are similar. In order to achieve sustainable paths forward, emphasis should be on identifying sustainable levels of collection with regards to the effects on marine ecosystems, terrestrial effects from beachcast removal (e.g. erosion), as well as environmental effects from the use of beachcast as fertiliser as agricultural use currently is the most common application.
- Gather and share knowledge to build capacity to support the development of legislation and policies which accommodate growth of sustainable macroalgae production systems - for cultivation, harvesting and collection.

2.3.1 Report on ecological impacts of macroalgae cultivation in the Baltic Sea region

In the recent years, the European marine waters have become a testing ground for macroalgae cultivation methods employed mainly in Asia, where most of the world's macroalgae are grown and harvested (van Oirschot et al., 2017). Macroalgae offer a means to increase food security, jobs and income while decreasing the nutrient load to eutrophic coastal areas and mitigating the eutrophication effects (Campbell et.al., 2019). For these reasons, macroalgae cultivation and harvesting is seen as a potentially socially, economically, and environmentally sustainable maritime activity, the development of which would support the EU blue growth strategy and blue bioeconomy initiatives.
The environmental conditions necessary for growing macroalgae vary among species. However, the key variables determining their growth are levels of sunlight, nutrients, salinity, and temperature. Due to the difference in these factors in the Baltic Sea the availability of wild grown, beach cast macroalgae and the possibility to cultivate currently commercially viable species varies12. Because of the environmental constraints, there are currently only a few types of macroalgae being cultivated and harvested in the Baltic1 and only a hand full of methods being applied2. This report is a summary of the environmental risks and, most importantly, the benefits of macroalgae cultivation in the Baltic Sea. It is well known that macroalgae need nutrients for growth and assimilate them from the surrounding environment. This is an important quality of macroalgae that could help overtime decrease the levels of phosphorus and nitrate in the Baltic marine environment. This report outlines in detail the ways in which nutrient removal could benefit the Baltic Sea ecosystem.

Conclusion

The report concludes that macroalgae serve as **carbon** and **nutrient sinks,** and their cultivation and harvest could mitigate the local effects of eutrophication and improve water quality. This would regulate and mitigate the occurrence of harmful algal blooms (Campbell et al., 2019; Duarte et al., 2017). Further, suspended macroalgae cultivation using longline systems at a small or medium scale is unlikely to have any significant negative impacts on marine ecosystems, if cultivation does not spatially overlap with sensitive or protected habitats. Large-scale cultivation or harvesting activities should take place with more caution. Large longline installations may introduce stressors over large areas for prolonged periods of time – shading extensive areas of the seabed and affecting communities of organisms underneath the installation and within the water column.

2.3.2 Guidelines for undertaking Environmental Impact Assessments for macroalgae cultivation and harvest projects

These guidelines aim to inform the local authorities, cultivators, and harvesters of the potential environmental impacts of macroalgae cultivation and harvest in the Baltic Sea. The guidelines briefly describe the current environmental management requirements regarding macroalgae cultivation and the Environmental Impact Assessment process in Europe. They also suggest criteria for evaluation of cultivation and harvest proposal and outline the expected environmental risks and benefits associated with longline cultivation of macroalgae in the Baltic Sea as well as harvesting of wild grown, loose lying macroalgae and beach cast wracks.

These guidelines have been put together following the European regulations regarding environmental Impact Assessments (EIA) using the most up to date scientific knowledge of the environmental impacts of macroalgae cultivation and harvesting in the Baltic Sea region. Further and more detailed information about the environmental impacts of macroalgae cultivation can be found in the GRASS project "Report on ecological impacts of macroalgae cultivation in the Baltic Sea region".

Conclusion

The approach to Environmental Impact Assessments will differ depending on the method of production (e.g. cultivation, hand-harvest or mechanical harvest). Sugar kelp (*saccharina latissima*) is currently the only major cultivated species in the Baltic, and there is a small amount of hand-harvesting which occurs. An EIA aims to inform the decision maker, or anyone else interested, of the consequences of the proposal and to identify mitigation measures that will minimize any significant environmental impacts. EIAs are part of the licensing procedure for plans, projects, and programmes, and are an EU wide requirement regulated by the EIA Directive (Directive 2011/92/EU). The EIA processes vary slightly from country to country, however the main stages are the same.

In practice, EIA is only applied to large scale, intensive fish farming projects, and because the majority of aquaculture projects are small scale, full EIAs are relatively rare (FAO 2009). While permitting procedures and EIA screening criteria for fish and shellfish aquaculture exist (European Commission 2016; Wood et al., 2017), they are yet to be interpreted and developed for macroalgae cultivation.

This is an issue, as the lack of formal procedures for cultivation projects and lack of understanding and regulation of risks creates uncertainty for developers (Wood et al., 2017) which could contribute towards the slow growth of the sector. Further, when it comes to wild harvest, national and local authorities and coastal communities across the world have begun voicing concerns that the rate and volume of harvest in some areas is unsustainable and may be causing damage to the ecosystems (Monogail et al., 2017).

2.4.1 Factsheet on the potential and environmental impacts of macroalgae harvesting and cultivation

Socio-economic benefits of sustainable macroalgae production in the Baltic Sea region

Marine macroalgae cultivation is an upcoming industry for food production without competing for arable or freshwater resources while removing excess nutrients from the water. Recent research reveals that macroalgal products might also provide useful source ingredients for pharmaceuticals and cosmetics industry. Nevertheless, commercial macroalgae production is still widely in its infancy and there is a lack of in-depth and wide-spread knowledge on the production potential of macroalgae in coastal waters. We are also largely unaware which ecological factors lead to high algal growth and how much algae could be potentially cultivated in aquaculture farms. To deal with this challenge, GRASS aims to build capacity on macroalgae cultivation, harvesting and the use among public authorities and other relevant stakeholders across the Baltic Sea region. Efficient management of marine resources is of key importance for achieving good environmental status in the European seas and blue growth of coastal communities.

Environmental benefits and risks

Seaweed remove nutrients and the process of cultivation does not require use of fertilisers. Therefore, seaweed harvesting and aquaculture can be seen as a way to decrease the nutrient levels to eutrophic coastal areas and to mitigate the negative symptoms of eutrophication. Different seaweed cultivation techniques interact with the environment in different ways. The magnitude of impacts depends on the method of cultivation, the surface area of the farm and the site where the farm is located. Significant improvements in the water quality can be expected in highly eutrophicated areas as in such environments positive impacts of seaweed farming are the highest. However, seaweed cultivation also presents some risks which are largely associated with large scale seaweed farming and harvesting including aesthetic impacts and changes to primary and secondary productivity levels.

2.4.2 Factsheet on the potential and environmental impact of beachcast production

Socio-economic benefits of sustainable beach-cast production in the Baltic Sea region

Harvesting of naturally occurring marine beach-cast and turning it into a marketable product (food, cosmetics etc.) offers an alternative avenue to macroalgal production while aligning with Blue Growth concepts. Beach-cast does have ecological functions such as providing food and habitat for sandy beach fauna, nutrients for dune vegetation, and protection for coastal dunes. Nevertheless, beach-cast is often considered a nuisance to humans due to the production of unpleasant odours when cast matter decomposes on the shoreline. This decomposition process also coincides with the production of carbon emissions. It has been estimated that the annual CO2-C flux from seagrass wrack globally is between 1.31 and 19.04 Tg C yr−1, which is equivalent to annual emissions of 0.5 – 9 million people depending on their geographic region. Thus, harvesting and removal of beach-cast while turning it into a marketable product offers a possibility to contribute reducing carbon emissions. Efficient management of marine resources is of key importance for achieving sustainable environmental status in the European seas and sustainable blue growth of coastal communities.

Environmental-ecological benefits/risk

The semi-enclosed Baltic Sea is very sensitive to eutrophication and collection of beach-cast could be an intervention to mitigate these processes. When macroalgae are collected we not only lower nutrients from the sea but we lower the ratio of nitrogen to phosphorus. The latter is important to decrease the eutrophication symptoms in the Baltic Sea region. However, different technologies and techniques used for collection of beach-cast will interact with the environment in different ways. The significance of impacts will depend on machinery and equipment used or amount of beach-cast algae harvested, and the site where the algae is gathered. Caution should be taken when choosing the sites for collection as beach-cast algae provide food and habitat for many invertebrates as well as birds. A removal of algae may disturb these habitats and species.

Implications and awareness

The decision-support tool (ODSS) for beach-cast growth production is accessible to everyone - from public authorities interested in harvesting beach-cast in their coastal region to private actors who want to get involved in the algae business. We spatially outline areas with expected high yields of beach-cast accumulation by which we (1) support decision-makers with the best tools for strategy development, resource allocation and spatial planning as well as (2) raise awareness and confidence in public sector towards balanced and environmentally friendly marine beach-cast harvesting in the Baltic Sea.

3.1 Maps illustrating MSP approach to best available sites for macroalgae cultivation in the Baltic Sea

The maps are publicly available and can be downloaded on this page: https://www.submariner-network.eu/grass

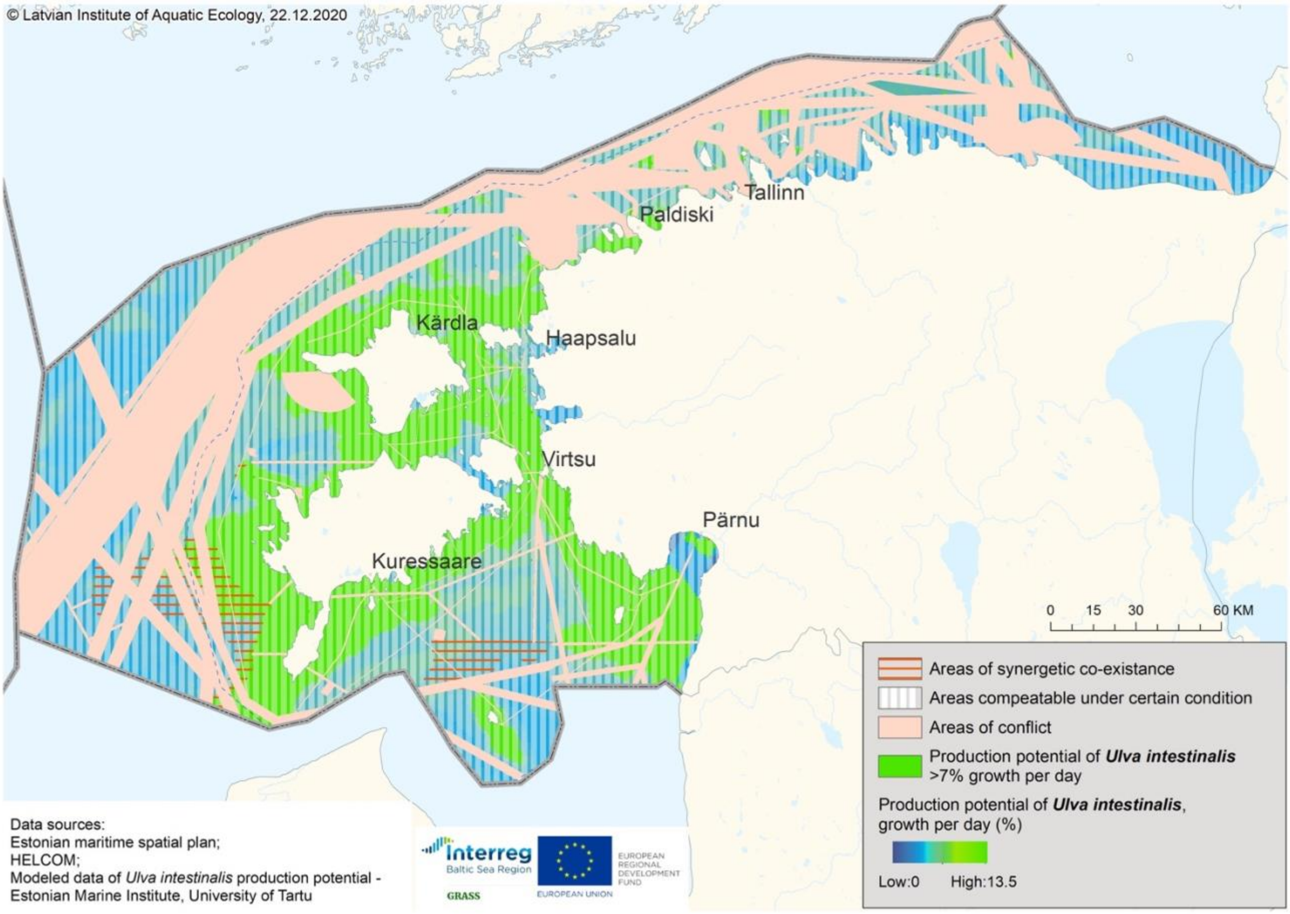

Figure 3: Example of Marine Spatial Plan maps for seaweed farms

3.2.1 European and National Regulations on Seaweed Cultivation and Harvesting

Figure 4: Seaweed farm in Sweden courtesy of Nordic Sea Farm

The Legislative Landscape on Macroalgae Cultivation

In Europe, cultivation (or aquaculture) of macroalgae is still at an early stage, as is the legislation. The EU and individual European countries lack seaweed-specific legislation, apart from the EU rules on organic seaweed (see below). The main EU legislations related to seaweed aquaculture are the Maritime Spatial Planning Directive 2014/89/EU, the Marine Strategy Framework Directive 2008/56/EC, the Water Framework Directive 2000/60/EC, the Alien Species Regulation 2014/1143/EU along with the Regulation on Aliens Species in Aquaculture 2007/708/EC, the Habitats Directive 92/43/EEC and the Regulation on Organic Production 2018/848/EU. Barbier and collaborators (2019) summarise the mentioned EU regulations and appoint the main challenges of applying these legislations on seaweed aquaculture as described below.

Maritime Spatial Planning Directive

According to the Maritime Spatial Planning Directive (MSPD) 2014/89/EU, each EU Member State needs to have Maritime Spatial Plans (MSP) based on an ecosystem approach to promote sustainable economic development and ecological protection. The development of seaweed aquaculture must be based on good management of space use, by promoting maximum production with minimum impact on the environment and coordinated with other maritime activities (Barbier et al. 2019).

Good Environmental Status

The Marine Strategy Framework Directive (MSFD) 2008/56/EC declares that member states must establish and implement a program of measures to achieve or maintain Good Environmental Status (GES) of the marine areas by 2020. Thus, aquaculture development should not negatively affect biodiversity and intertidal ecosystems, should not contribute to the introduction of invasive species, and should not contribute to eutrophication of coastal areas or the open sea (Barbier et al. 2019). Similarly, for inland surface, transitional, coastal and ground water, the Water Framework Directive (WFD) 2000/60/EC establishes a framework for the protection and enhancement of good status.

Alien Species Regulation

Aquaculture development should not negatively affect biodiversity or increase eutrophication (Barbier et al. 2019). The goal of the Alien Species Regulation 1143/2014 EU is the prevention and management of the introduction and spread of invasive alien species. There is a special regulation 708/2007 for protecting aquatic habitats from the use of alien and locally absent species in aquaculture. According to Barbier et al. (2019), the list of invasive alien species needs to be harmonized in the EU specifically concerning alien species that have long been used in aquaculture.

Habitats Directive and Biodiversity

The goal of the Habitats Directive (92/43/EEC) on the conservation of natural habitats and wild fauna and flora is to promote biodiversity by protecting natural habitats and species, contributing to the sustainable development of ecosystems at the EU level. Natural habitat types of community interest include coastal and halophytic habitats, specifically open seas and tidal areas with reefs. Thereupon, aquaculture development should be compatible with the protection of natural habitats and biodiversity (Barbier et al. 2019).

Environmental Impact Assessments

The Environmental Impact Assessment Directive 2011/92/EU and its amendment 2014/52/EU lay down the procedure for conducting environmental impact assessments of private and public granted projects such as aquaculture before activities begin. In the category of fish farming there is no mention of seaweed, but large-scale operations might require impact assessments.

Organic Seaweed

Organic seaweed has its own regulatory category. The Commission Regulation 2009/710/EC lays down detailed rules on organic seaweed production. The Regulation on Organic Production 2018/848/EU on organic production and labelling of organic products applies, defining the production rules for algae, including harvesting of natural stocks as well as their cultivation (see *Part III: Production rules for algae* *and aquaculture animals, 2. Requirements for algae*). The collection of wild algae and parts thereof is considered as organic production provided a) the growing areas are suitable from a health point of view and are of high ecological status as defined by Directive 2000/60/EC and b) the collection does not affect significantly the stability of the natural ecosystem or the maintenance of the species in the collection area. Furthermore, the amounts collected should not cause a significant impact on the state of the aquatic environment. Organic macroalgae aquaculture at sea shall only utilize nutrients naturally occurring in the environment, or from organic aquaculture animal production, preferably located nearby as part of an Integrated Multi-Trophic Aquaculture (IMTA) system. Culture density or operational intensity shall be recorded and shall maintain the integrity of the aquatic environment by ensuring that the maximum quantity (environmental carrying capacity) of algae which can be supported without negative effects on the environment is not exceeded. Ropes and other equipment used for growing algae shall be re-used or recycled where possible.

Specific regulations on seaweed cultivation at the EU level are missing but there are several regulations and directives that can be applied to it. Here, we emphasize the importance of the MSPD 2014/89/EU, and the MSFD 2008/56/EC to facilitate the regulation and development of this new industry. In general, all the GRASS and SUSCULT countries have adopted, or are in the process of adopting, an MSP to manage the use of the marine areas by defining the relevant sectors for human activities and to ensure a sustainable procedure. Based on the EU MSPD, all the EU members must stablish their marine spatial plans by 2021. In general, all the countries include aquaculture and/or fishing activities in their plans, but seaweed cultivation is not mentioned. However, in some of the countries such as Finland, Sweden and Estonia, seaweed cultivation is mentioned in their MSP vision towards 2030. These countries emphasis the potential uses of seaweed in different industries, including the blue biotechnology sector, and their environmental benefits by using seaweed cultivation as a compensation measure for removing nutrients. Also, the studied countries have established Marine Strategies in order to achieve, or maintain, a good environmental status based on the EU MSFD regulation, which had to be implemented by 2020. Almost all the GRASS countries, including Denmark, indicate the potential uses of this raw material for different industries. Although it is not sufficient, the mention of the potential benefit of seaweed in the national MSP and Marine Strategies is a big step towards an improvement in the regulation and licensing process of this activity.

The same occurs at the national level, specific regulations on seaweed cultivation are largely missing in the GRASS partner countries (Finland, Estonia, Latvia, Sweden, Germany, Poland, Russia). In GRASS neighbouring countries (Iceland, Norway, Denmark, Lithuania), the situation is similar. Lithuania is the only country that does not require licenses for seaweed aquaculture. The general aquaculture and fishing permit procedures and the general environmental and water laws apply to seaweed cultivation. However, there are some exceptions: Estonia, Iceland, Norway, Germany and Russia have rules on wild seaweed harvesting and Denmark and Norway have specific seaweed permits. Because the environmental impacts of seaweed cultivation differ entirely from (or in fact counteract) those of fish aquaculture, entrepreneurs, researchers, and regulatory authorities must come together for setting up good regulatory practices that specifically applies to seaweed cultivation. Regulatory collaboration and/or benchmarking between countries is preferable. All Baltic states may want to sign and endorse the

UN Global Compact Seaweed Manifesto (2020), which is the first global memorandum of understanding on seaweed.

Conclusions

Licensing aquaculture activities can be a long and tedious process for entrepreneurs, in some cases taking several years. The lack of specific seaweed legislation is one of the main obstacles for seaweed aquaculture. The authorities must understand what seaweed is, and the benefits that it can generate. Having a specific regulation on seaweed aquaculture may accelerate the licensing process, which would benefit all the interested parties including authorities, entrepreneurs and stakeholders. The development and improvement of the seaweed market by promoting this business with workshops, stakeholders' meetings and conferences may increase the interest of the authorities on regulating the seaweed related activities. Awareness-raising and pilot farms are also needed to arouse the interest in politicians and administrators. Governments may refer to global standards, mainly the ASC-MSC Seafood Standard (Aquaculture Stewardship Council and Marine Stewardship Council 2018) in determining the rules for sustainable macroalgae business.

Figure 5: Fucus vesiculosus

3.2.2 Policy Brief #1:
Promoting Sustainable Macroalgae Business

Macroalgae, or seaweeds, are simple, plant-like organisms found worldwide. They grow primarily along the coastline, but they can also be found in freshwater ecosystems such as rivers and lakes. Macroalgae are divided into three major groups: green, brown and red algae. The global value of the macroalgae industry is currently more than 6 billion USD (FAO 2019), out of which 85% comes from food products for human consumption (FAO 2018). In the last decade, the global cultivation of macroalgae has doubled to an annual production of 32 million tons fresh weight (FW), whereas the harvesting of natural macroalgae has stayed constant at approximately 1 million tons FW per year (FAO 2019). According to Seaweed for Europe Coalition (2020), European seaweed production will have to rapidly expand from present production of 300,000 tons FW (2020) to 8 million tons FW by 2030, to cover 30% of the need of the European seaweed industry, with an estimated market value of €9.3 billion in 2030.

The benefits of macroalgae/seaweeds

Macroalgae biomass is a rich source of bioactive products. Relevant macroalgae end uses include medicinal products, food (direct consumption, food ingredients, supplements, and additives), feed and feed additives, cosmetics, bioplastics, fertilizers and agricultural biostimulants, and biofuels/biogas. Due to their high protein content, favorable amino acids, antioxidants and vitamins, macroalgae have many benefits for humans (SAPEA 2017). MOST IMPORTANTLY, macroalgae do not need land, fertilizers or freshwater in their production. Macroalgae production can mitigate the effects of eutrophication and enhance water quality through nutrient uptake. Algae production mitigates climate change through binding CO2 in algal biomass. According to Seaweed for Europe (2020), 27,300 hectares of macroalgae farms can take up 20,000 tons of nitrogen, 2,000 tons of phosphorus and 5.4 million tons CO2e. In sum, macroalgae can have a significant role in reaching various sustainable development goals related to food security, human health, and planetary health, in addition to providing opportunities for sustainable blue economic growth.

Further research and better regulation

Further research and innovation activities are needed to discover the potential of various algal species, to develop cultivation methods, to ensure product safety, and to respond to consumer needs. Macroalgae should be understood both as a bioeconomy resource and as a potential tool for environmental management. All Baltic states should sign and endorse the UN Global Compact Seaweed Manifesto (2020), which is the first global memorandum of understanding on seaweed.

The European and national regulations on macroalgae cultivation and macroalgae products must protect consumers and the environment while not discouraging sustainable innovation. Governments may refer to global standards, mainly the ASC-MSC Seafood Standard (Aquaculture Stewardship Council and Marine Stewardship Council 2018) in determining the rules for sustainable macroalgae business. The licensing procedures for macroalgae cultivation in the sea are a central regulatory issue. Permitting is based on environmental and water law. For EU Member States, the Maritime Spatial Planning Directive 2014/89/EU, the Water Framework Directive 2000/50/EC, the Marine Strategy Framework Directive 2008/56/EC, and the Habitats Directive 92/43/EEC are central. Multi-use of sea and synergies between sectors can be promoted through maritime spatial planning: macroalgae cultivation can co-locate for example with offshore wind farms. As an opposite to fish aquaculture, macroalgae cultivation can potentially improve water quality by reducing nutrient loads in the ecosystem. Macroalgae can be part of Integrated Multi-Trophic Aquaculture (IMTA) systems, where macroalgae can offset nutrients released from fish or mussel farming. Macroalgae cultivation is a new activity in the Baltic Sea region, and the Baltic Sea countries do not have specific regulations on the activity. In many countries, several different authorities are involved in aquaculture licensing, and the procedure is time-consuming. One-stop shops for macroalgae cultivation and IMTA permits are needed, even in federal countries if possible. A joint statement from the ministries and permitting authorities ex-pressing a favourable attitude towards macroalgae farms would encourage the business.

The regulations on macroalgae products are another critical issue for the development of this industry. Improving and clarifying the European rules on macroalgae products is mainly a task for the EU. The novel food status (Regulation 2015/83/EU) of some edible macroalgae species has not yet been evaluated and clarified. Uniform safety rules are needed as regards heavy metals and toxins in macroalgae foods (under Commission Regulation 2006/1881). Fishery product labelling rules (Regulation 2013/1379/EU) seem unsuitable for macroalgae products, and health claim substantiation (Regulation 2006/1924/EU) is demanding for any food company. THE MARKETS for macroalgae products are importantly shaped also by the more general regulatory instruments impacting either the supply of macroalgae products or their demand. Many macroalgae products have their added value in replacing more resource intensive, larger-carbon footprint and less healthy alternatives such as meat or soy. A regulatory framework that adds weight to sustainability criteria will work in their favor:

- **Recognising macroalgae** cultivation and wild harvesting as a **compensation measure** for nutrient and carbon emissions promotes innovation in multi-trophic biocircular systems. In addition to selling the biomass, algal biomass producers could receive income through tradeable offsets.
- **Public Procurement** rules that add weight to environmental criteria broaden the markets for eco-innovative products. European procurement policies are based on European and national laws, but concrete procurement criteria are decided at the level of individual procurement units.
- **Tax Schemes** that add weight to environmental criteria benefit sustainable products. The EU sets the amount of possible VAT rate categories (a Member State can have three), whereas tax rates are decided at Member State level.
- **Trade Agreements** between the EU and other countries or trade blocks may adopt criteria that favor sustainable products while blocking or limiting the imports of unsustainable products.
- **Removing Subsidies** from the production of competing, high-carbon raw materials lowers the relative prices of more sustainable products.

3.2.3 Policy Brief #2:
How to reconcile blue growth with environmental objectives in the Baltic Sea

This policy brief aims to guide decision-makers on how to regulate novel blue biomass solutions in the Baltic Sea region. Legal regulation should provide possibilities for both blue growth and for environmental protection. Novel blue biomass solutions include macroalgae cultivation, mussel farming and reed and fish biomass removal from the sea.


Figure 6: Bladderwrack (Fucus vesiculosus)

The aim of the European Union's Blue Growth strategy is to harness the untapped potential of oceans, seas and coasts for jobs and growth in a sustainable way (European Commission 2012, 2020). The European Green Deal underlines that the blue economy must be able to protect and restore nature and fight climate change in addition to providing economic growth and employment (EU 2020). FOR BLUE economy to be environmentally sustainable, it must comply with EU environmental law requirements stemming from the EU Water Framework Directive (WFD 2000/60/EC), Marine Strategy Framework Directive (MSFD 2008/56/EC) and Habitats Directive (92/43/EEC).

The environmental sustainability requirement is particularly challenging in the Baltic Sea region due to severe eutrophication resulting in, for example, harmful algal blooms. In order to achieve and maintain a good environmental status of the Baltic Sea in accordance with WFD and MSFD, not only does the nutrient inflow from the catchment area of the Baltic Sea need to be reduced but also nutrient uptake and removal has to be enhanced (Schultz-Zehden et al. 2019; Baltic Blue Growth 2019). THE BLUE biomass solutions may prove crucial in the nutrient uptake from the Baltic Sea. Such solutions remove excess nutrients and thus reduce the effects of eutrophication. Simultaneously, they provide possibilities for circular economy approaches in combination with aquaculture, animal husbandry and agriculture. THIS POLICY brief discusses the EU blue growth objectives (Section 2), the EU environmental objectives (Section 3) and their reconciliation through the novel blue biomass solutions in the Baltic Sea area (Section 4). Finally, the policy brief proposes guidelines for the regulatory reforms at national level to enhance the utilization of novel blue biomass solutions (Section 5).

The WFD, MSFD and BSAP all require countries to reduce eutrophication of the Baltic Sea. To achieve that, it is impor tant to not only to reduce nutrient inflow but to also develop nutrient uptake and removal as a mitigation strategy. Thus, the WFD, MSFD and BSAP allow and even support blue biomass solutions as far as they contribute to the achievement of the environmental objectives (see Schultz-Zehden et al. 2019). Considering the reconciliation of blue growth and the environmental objectives in the Baltic Sea, the relationship between fish farming and the novel blue biomass solutions provides a concrete example. Regarding fish farming, both open-net rearing units and recirculating systems, cause nutrient inflow to the sea. Therefore, it is uncertain whether any new or continued permits can be granted for fish farming in areas that have not achieved the environmental objectives of WFD and MSFD (see Soininen et al. 2019). To allow permitting, EU Member States may consider different measures, such as the biomass solutions, to remove nutrients from the sea (EU 2017).

National policy measures needed

MARINE AND coastal aquaculture in the Baltic Sea comprises of fish farms, mussel farms and algae cultivation. Fish farms are operated on a commercial basis, while mussel farms and algae cultivation, which are two of the novel blue biomass solutions, are currently (2021) mostly pilot-scale research projects (Przedrzymirska et al. 2019). ACCORDING TO the EU, the blue bioeconomy faces many challenges and constraints. Two of these are the complexity of the regulatory and administrative procedures and the lack of reward schemes for the provision of environmental services to the marine ecosystems (EU 2020). THE WATER Framework Directive, Marine Strategy Framework Directive and Baltic Sea Action Plan all support novel blue biomass solutions that enhance the achievement of the good environmental status of the Baltic Sea. However, they also leave a lot of discretion for Member States to regulate the biomass solutions and to reconcile them with the blue growth objectives (see Schultz-Zehden et al. 2019). AT THE national level, the advancement of the novel blue biomass solutions requires different types of policy measures. On the one hand, a lot can be done based on current legal regulation. On the other hand, legislative changes may also be needed.

1. Promote novel blue biomass solutions through maritime spatial planning

O N E O F the bottlenecks of the novel blue biomass solutions is the integration of the different uses of marine areas. Macroalgae cultivation, for example, may require large marine areas of operation and must be integrated with nature conservation areas and other activities such as shipping, fisheries, wind power production, recreational uses and national defence. Some of these uses, e.g. offshore wind energy, may be combined with blue biomass solutions (see Przedrzymirska et al. 2019). Furthermore, space on land is needed for the storage and processing of wet algal material. ONE OF the policy tools to enhance macroalgae and other novel biomass solutions at sea is maritime spatial planning. The main objective of the EU Maritime Spatial Planning Directive (2014/89/EU) is to promote sustainable development and growth in the maritime sector (Art. 5). To achieve this, maritime spatial plans should be able to reduce conflicts between sectors, create synergies and balance the development of a wide range of maritime activities (EU 2016). Maritime spatial planning process can specifically address the novel blue biomass solutions. In addition, regional and local level planning is needed to enable the storage and processing of blue biomasses.

2. Plan how to manage nutrient balances.

Novel blue biomass solutions could benefit from a mass balance approach to evaluate the nitrogen and phosphorus pools at the Baltic Sea level and the national level. In the framework of the Baltic Sea Action Plan, states could consider how to allocate their nutrient targets between different activities and how the novel blue biomass solutions may support synergies between sectors or offset emissions from other activities by removing nutrients from the sea. THE BLUE biomass solutions can also be included in the river basin management plans and marine strategies. In this way, countries may plan in more detail how they can use these solutions as environmental measures to offset nutrient loading resulting from different sea- and land-based activities. TO MITIGATE eutrophication stemming from the fish farming, Member States may consider applying nutrient-neutral schemes and other means to remove nutrients from the sea (EU 2017). National and international nutrient trading schemes and co-location solutions could be enhanced. They could include the development of integrated multitrophic aquaculture systems where fish farms are combined with nutrient extracting species such as macroalgae or shellfish to provide environment remediation in the form of the bio-mitigation of harmful impacts (see EU 2016; Przedrzymirska et al. 2019).

3. Recognise blue biomass solutions as environmental measures

Novel blue biomass solutions should be officially recognised as a nutrient mitigation tool. This could provide incentives to support these solutions and their use as nutrient offsetting/compensation measures in relation to economic activities (see Submariner 2019). However, at the same time the environmental impacts of these solutions, such as large-scale macroalgal cultivation, must be monitored, since they may disturb marine ecosystems (Suutari et al. 2016). An extensive assessment on their total environmental and socio-economic footprint should be conducted. ECONOMIC INCENTIVES are needed to develop infrastructure for the blue biomass solutions (see Suutari et al. 2016). There could be payments for the ecosystem services they provide. While different public funding schemes are available for the purpose, payment schemes could also be based on markets for ecosystem services either under the polluter pays or beneficiaries pay principle (Schultz-Zehden et al. 2019).

4. Make permitting work

Public authoriation relates to novel blue biomass solutions in two ways. First, these solutions usually require a permit due to their need of marine operation area. Second, they can be supported as environmental measures through the permitting of other activities such as fish farming. TO MAKE the permitting of the blue biomass solutions work, these solutions should be integrated into planning instruments. Maritime spatial planning as well as the river basin management plans and marine strategies provide a platform for the permitting process to locate and permit the blue biomass activities and, in general, to reconcile them with other uses of marine environment. Second, the largely positive environmental impacts of the blue biomass solutions should guide the permitting process and required environmental assessments. The lack of understanding of the environmental impacts of novel blue biomass solutions (e.g. mussels and seaweed farming) may cause lengthy permitting processes. Public and private sectors should work together to help with the knowledge gap concerning these solutions and provide sufficient information, such as recommendations and guidelines, to the authorities. WHEN PERMITTING fish farming or other activities causing nutrient loading to the sea, blue biomass solutions should be considered as environmental measures that may help with mitigating or offsetting their impacts. States could help develop trading schemes that consider the ecosystem services that blue biomass activities provide and consider the cumulative impacts of different activities (EU 2016; Belinskij et al. 2018).

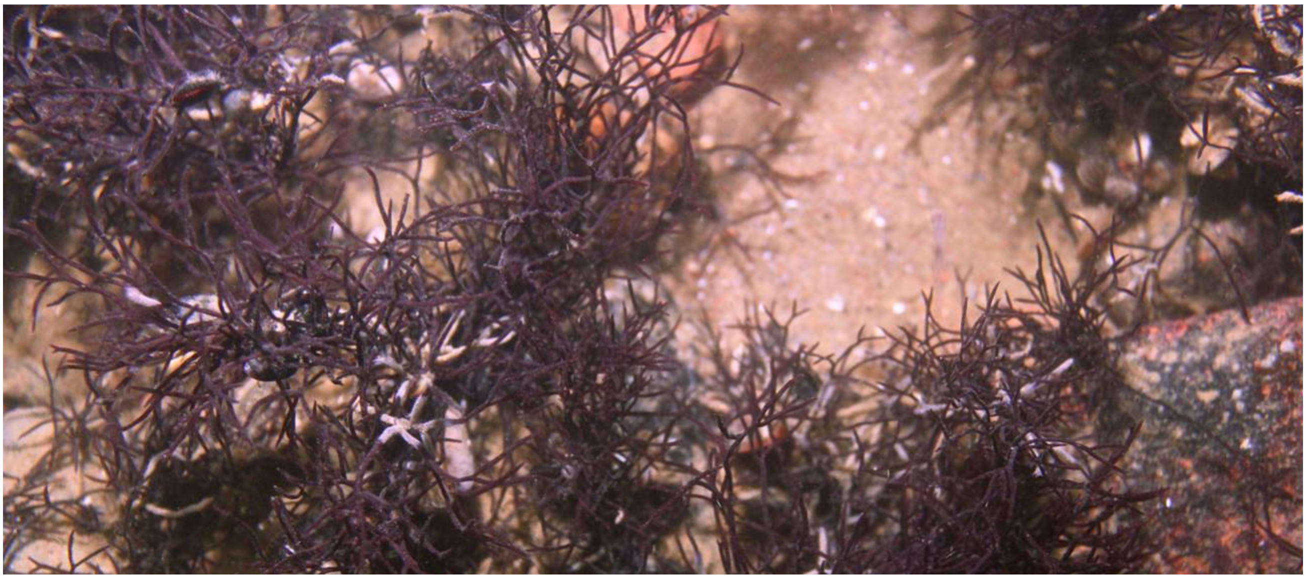

Figure 7: Furcellaria lumbricalis

3.3 Knowledge dissemination and transfer of GRASS (international conference)

Figure 8: The GRASS Final Conference was hosted online

A summary of the international conference can be found here:
https://www.submariner-network.eu/news/75-grass-news-and-events/924-the-final-grass-conference-making-waves-across-the-baltic

Dissemination Plan

This dissemination plan focuses on how, when and to whom to communicate the GRASS project results and outputs in order to reach maximum impacts. The list of outputs included in this strategy presents the specific dissemination tools to be used, along with target groups, date of finalisation/publication and subsequent dissemination. The dissemination strategy in this document focuses on how the results of the GRASS project are to be communicated to which actors or networks, emphasizing a targeted approach. The project activities, goals and key messages will be communicated and disseminated continuously to external target audiences throughout the project lifecycle, in particular to relevant stakeholders, target groups and end-users. The dissemination of maps, manuals, factsheets, and reports on macroalgae legislation and cultivation are the key outputs of the project, thus the targeted distribution of information to key stakeholders is crucial to the success and legacy of the project.

These outputs are intended as a set of decision support tools for other projects, networks and crucially policy-makers, to increase awareness and capacity for seaweed cultivation and harvesting in the BSR. For this purpose, GRASS is proactively informing these networks and actors about relevant project news, events and project outputs through established contacts with their respective communication officers, and in turn sharing news from external networks through the GRASS website and newsletter. Basic information regarding the project, related news, events and outputs are regularly posted on the project website, as well as through a newsletter every four months and being shared through partners' external dissemination channels (e.g. newsletters, events or social media). The project flyer is available online for all project partners and is regularly disseminated at events of strategic interest. Dissemination of outputs will be finalized among the project partners via 5 partner meetings, 18 regional stakeholder meetings and together with associated organizations and the general public via an international GRASS conference to be hosted by the SUBMARINER Network as an online webinar. Beyond the published documentation throughout the course of the project, GRASS' legacy will also be in the establishment of a transnational macroalgae working group. This network of cross-disciplinary stakeholders will be the foundation for future collaborations and the basis for relevant project proposals in the future.
The coordinated approach to communication of project activities and outputs will aim to achieve an impact greater than the sum of their individual parts. Awareness raised and connections made throughout the project will result in an open-source map of macroalgae resources, barriers, opportunities and stakeholders, thus forming the foundation for further development of the sector within the Baltic Region and beyond. The legacy of the project will therefore be threefold:

1. Expertise gained through project activities, facilitating in-depth research and knowledge transfer between partners and stakeholders.

2. A network of public bodies, research institutes, NGOs and business actors with a mutually beneficial interest in macroalgae cultivation in the BSR. This network will form the basis for a macroalgae working group to maintain the momentum from the project into future projects and collaborations.

3. Physical outputs in the form of online tools as well as various factsheets, manuals, reports and knowledge kits on the regulation, impacts and opportunities of macroalgae production in the Baltic Sea. These can in turn be used as reference material for future project proposals, funding applications, lobby groups, business plans and educational programmes.

The post-project macroalgae working group will provide a platform for transdisciplinary stakeholders and newcomers to interface on various topics from licensing to marketing, thereby facilitating knowledge transfer and pooling of resources to achieve critical mass required to develop the sector further. The working group will meet regularly and build on relationships with local, regional, national and intergovernmental organizations established through the GRASS project, facilitating further collaboration through mutual understanding and increased capacity. For example, GRASS partners are already connected with the Seaweed for Europe Coalition: a bottom-up, industry-led European network promoting large-scale seaweed production. SUBMARINER Network and other partners are participating in the Coalition's action groups, thus promoting knowledge transfer within key target groups.

3.4.1 Inventory and dossier of existing relevant EU safety regulation and its national application

Macroalgae are a diverse group of organisms comprising roughly 10 000 different species that vary in size, shape and type of lifecycle. Macroalgae are further divided to brown, red and green algae. Edible species are found across all three groups but are a small fraction of the total number of species. In addition to species that are considered edible sea vegetables, various macroalgae species are used for extraction of additives, like colorants and gelling agents, utilized in the food industry. Macroalgae are nutrient rich ingredients for food and feed and have long history of consumption at coastal areas throughout the world. Macroalgae are intriguing ingredients for food and feed as they typically have high content of fiber, minerals, antioxidants and vitamins. Many edible species are especially rich in vitamins A, K and B12. Moreover, seaweeds have typically low fat content with high relative abundance of polyunsaturated fatty acids (PUFAs) like docosahexaenoic acid (DHA). The protein content varies between genera and is typically higher in green and red macroalgae (approximately 10−47% dry weight) and low in brown algae (Fleurence et al., 2018). Importantly, unlike many plant protein sources, macroalgae contain all essential amino acids for human and animal nutrition. Furthermore, macroalgae can be used to enhance flavor and as a healthier alternative to salt. Finally, seaweeds harbor a variety of delicate and interesting aromas. Kombu (Saccarina japonica) has a rich umami flavor and Palmaria palmata is called sea bacon due to its smoky aroma.

Seaweed usage in Europe has been minor but interest towards its consumption is increasing. Also the European Commission (EC) has recognized macroalgae as important marine resource with potential as food and feed (European Commission, 2017). The use of macroalgae as food and feed in the European Union (EU) is under regulation by the EU food and feed legislation. This report summarizes the EU policy framework that regulates the use of macroalgae as food and feed in the EU member countries. Moreover, this report gives a brief overview of the seaweed production in Europe and the use of macroalgae as food in the Baltic Sea region.

Conclusions

Macroalgae have newly been recognized as potential food and feed ingredient in Europe and in the Baltic Sea countries, where their consumption has traditionally been less compared to other regions. With the increased consumption of imported seaweed products, also the interest towards local seaweeds is starting to rise. The Novel Food law still limits the use of many European macroalgae species as food, although the authorization processes have been developed and simplified. Moreover, the food safety regulation setting limits to harmful contaminants in food suffers from shortcomings concerning the seaweed food products. Maximum levels for arsenic in seaweed foodstuffs have not been established even though high levels of inorganic arsenic in certain macroalgae species may result in the intake of harmful quantities of inorganic arsenic even when relatively small amounts of seaweed are consumed.

However, these shortcomings in the regulation have been recognized and are likely to be resolved in the future. The classification of seaweeds as fishery and aquaculture products is noteworthy, since it obligates detailed product labeling and authorization of the species by the national authorities. The limitations and requirements for macroalgae based feed materials are established in the EU feed laws where, depending on the regulation, algal feed materials are either considered as their own feed category with specific safety regulations or covered by common principles applicable to all feed materials.

Figure 9: Sugar kelp (Saccharina latissima)

3.4.2 Report on the use of macroalgae outside the EU

Macroalgae are a diverse group of aquatic organisms that have been utilized by mankind for multiple purposes for thousands of years. Macroalgae are used as fresh or mildly processed in foods and consumables. Moreover, they are used as raw material for various extracts, the most important ones being agar, alginates and carrageenan. Currently, the use of biologically active macroalga extracts as food and feed supplements is growing. In addition, there is interest towards novel macroalga based food additives such as food flavours, colourants and nutrients. Macroalgae are divided into three classes: green, red and brown macroalgae (Chlorophyta, Rhodophyta and Phaeophyta, respectively), of which the brown macroalgae species are the commercially most important ones counting for two-thirds of the globally produced macroalga. Brown macroalgae are followed by red macroalgae with a share of approximately one-third and green macroalgae with a share of 5% of the global macroalgae production (Lorenzo et al. 2017). Currently, over 200 macroalga species are used globally and the total production reaches over 30 million tons. Regardless of the diversity of edible and otherwise useful macroalga species, 98% of the seaweed production is accounted for only five macroalga genera (Pereira et al. 2008, Table 1). Utilisation of more diverse species suffers from various bottlenecks including lack of suitable cultivations techniques as well as of the limited distribution and natural abundance of species. Moreover, research on the biochemical composition, nutritional and bioactive properties and sensory characteristics of novel seaweeds is needed to unlock their potential as food or source of natural compounds.

Conclusions

While macroalga hydrocolloid production and traditional macroalga based foods remain big sectors of macroalgae industry, interest towards new products such as macroalgae food supplements and novel macroalgae consumables is evident. Although the diversity of the currently used macroalgae species is wide, lack of efficient cultivation technologies has a big impact on the production volumes of different macroalgae species. Harvesting of wild macroalga populations is often unsustainable and utilisation of many macroalgae species is dependent on development of new aquaculture techniques. Diverse selection of sustainably produced macroalgae species would allow the development of novel macroalgae food and feed products and novel high-value phytochemicals. In addition, subsequent extraction of various fractions and raw materials from macroalgae biomass and utilisation of side streams of the hydrocolloid production could bring higher revenue for the macroalgae production. However, more research is still needed to unlock the potential of macroalgae phytochemicals for different applications.

3.4.3.1 Set of guidelines for macroalgae production for human consumption: Health benefits and potential for the food industry

Macroalgae are a rich source of nutrients and a versatile raw material for multiple food industry applications. Macroalgae cultivation offers a sustainable production platform that can be harnessed for production of nutritious food products, food additives and high-value bioactive compounds.

Nutritional content

Marine macroalgae have a superior content of essential mineral nutrients compared to land plants. Macroalgae contain calcium, potassium, magnesium, zinc, iron, manganese, copper and iodine. Moreover, macroalgae are a good source of both water-soluble and fat-soluble vitamins like vitamin C and vitamin A, respectively. In addition, macroalgae are a rare non-animal source of vitamin B12. Many green and red macroalgae species have high protein content and contain all essential amino acids for human nutrition. Macroalgae are also a rich source of soluble dietary fibre. Therefore, many edible macroalgae contain, for example, enough fiber or mineral nutrients like iodine for the use of nutrition claims “high fiber” or “high iodine”, in the product packaging. Permitted nutrition claims and the required levels of nutrients in foods are defined in regulation (EC) No 1924/2006.

Health benefits

Macroalgae contain a range of bioactive compounds including fibers, phenolic compounds and pigments. These compounds have documented health benefits like antioxidative and anti-inflammatory activities. Moreover, they modulate metabolism and promote healthy gut microbiota. However, more research is still needed on the bioavailability and activity of the different compounds. Currently, the EU regulation (EU) No 432/2012 of permitted health claims does not include any authorized health claims for macroalgae foods. However, the high content of mineral nutrients in macroalgae may justify the use of health claims related to individual nutrients like iodine.

Possibilities for the food industry

Most edible macroalgae can be used for food as fresh or dried and cooked. Globally, red and brown algae are important raw material for gelling and thickening agents carrageenan, agar and alginates. Moreover, macroalgae are a promising raw material for production of novel food additives like pigments or antioxidants. Macroalgae extracts may be used as food supplements or to fortify food products with nutrients or bioactive compounds. In addition, macroalgae are an intriguing possibility for sustainable production of protein for human consumption.

Key messages and recommendations

- Macroalgae are a rich source of mineral nutrients, vitamins, fiber and protein
- Macroalgae contain multiple bioactive compounds that are currently under active research
- Many macroalgae food products fulfill the nutritional requirements for the use of nutrition claims in the product packaging and for health claims related to individual nutrients
- Macroalgae may be used for extraction of multiple high-value compounds and fractions with applications in the food industry

3.4.3.2 Set of guidelines on macroalgae production for human consumption: Risks and food safety regulation

Macroalgae are a promising raw material for a wide range of consumables and food products in the Baltic Sea region. Diverse edible macroalgae species can be used as consumables, taking into account food safety and regulatory limitations.

Heavy metals and contaminants

Macroalgae readily accumulate minerals from the surrounding water at their growth location. Unfortunately, macroalgae are also prone to accumulate toxins such as heavy metals including lead, arsenic, mercury and cadmium. This natural ability to accumulate toxins must be considered when macroalgae are harvested or cultivated in potentially polluted sea areas. At the moment, maximum limits for heavy metals have not been defined for macroalga food products specifically in the EU. As an exception, the maximum level for cadmium in food supplements consisting of seaweed or of products derived from seaweed is 3,0 mg/kg (weight as sold) ((EC) No 1881/2006).

Iodine

Macroalgae are a good source of iodine and a healthy alternative to iodized salt. However, especially brown macroalgae species may have very high iodine content that sets limitations to their use as food. Adequate intake for iodine set by the European Food Safety Authority (EFSA) is 150 µg/day for adults1. Moreover, tolerable upper intake level of 600 µg /day for adults has been recommended by EFSA and 1100 µg / day by the World Health Organization (WHO)1,2. With some brown macroalgae these limits may be exceeded already with very a small daily serving size. High consumption of brown macroalgae may impair thyroid health and thus the iodine content should be marked on the product labels. Variation in iodine content between and within species poses challenges for the food industry and product labelling. Iodine content can be reduced by food processing.

Food safety of novel macroalgae species

Food use of novel macroalgae species in the EU is regulated by the Novel Food regulation (Regulation (EU) 2015/2283). Status of different macroalgae species as novel foods may be consulted from the Novel Food Catalogue (https://ec.europa.eu/food/safety/novel_food/catalogue_en) and national food safety authorities. Novel Food regulation covers also the use of novel macroalgae species and macroalgae extracts as food supplements. If a macroalgae species or extract is considered a novel food, it needs to pass a safety assessment by EFSA and an authorization procedure to enter the EU market.

Key messages and recommendations

• Possible accumulation of heavy metals to macroalgae should be considered when choosing the cultivation or harvesting site to produce macroalgae for food purposes.
• Macroalgae producers and retailers should be aware of the levels of heavy metals in their macroalgae food products.
• Iodine content of macroalgae should be marked to the product labels and consumers should be alerted in case the iodine content is high.
• Novel macroalgae species and macroalgae extracts need authorization before they can be sold as food or food supplements in the EU.

Figure 10: Fucus vesiculosus and seagrass (Zostera marina)

4.1 Report on macroalgae value chains relevant for BSR, showcasing macroalgae business models for blue bioeconomy products and market analysis

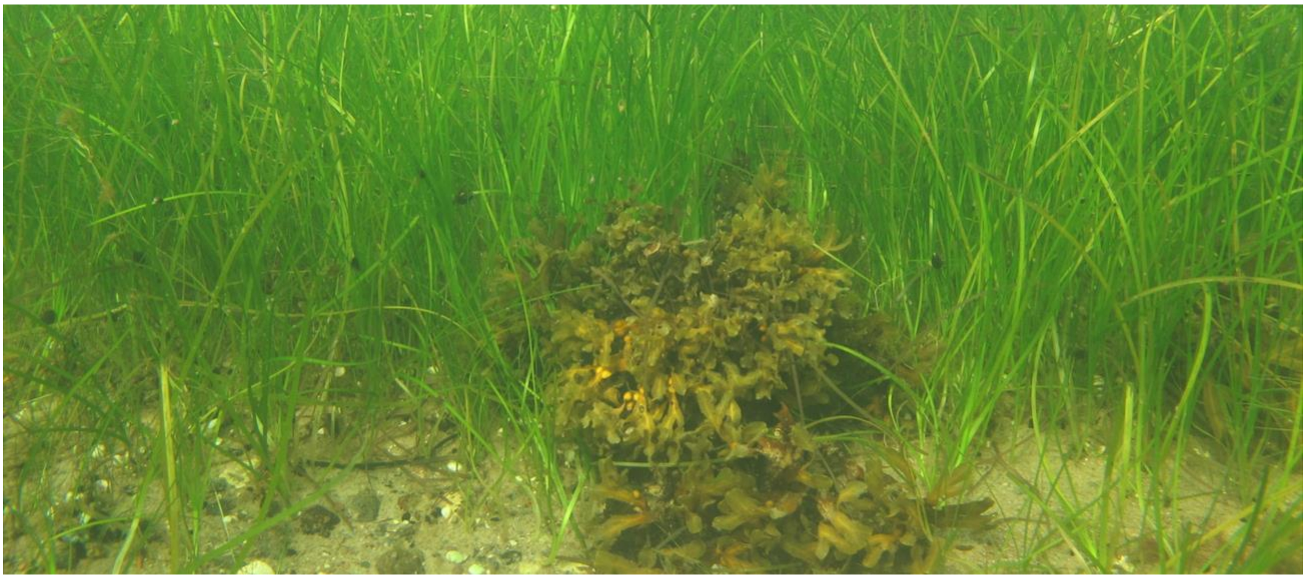

Figure 11: Fucus vesiculosus and seagrass (Zostera marina)

Asian countries produce the majority of the macroalgae biomass and also cultivate the greatest diversity of seaweed species. Although more than 200 species of macroalgae are exploited commercially, five genera represent approximately 98% of the world seaweed production. Macroalgae are commercially processed mainly for food products and production of hydrocolloids. However, due to the presence of various valuable compounds, which are suitable for e.g. pharmaceutical, biomedical or cosmetic industry, more and more new products are available on the market and additional ones are in the research phase. In 2005-2015, the global production of seaweed doubled, but in 2016-2018 the dynamics of the development of seaweed production decreased significantly. The vast majority of production is made in Asia. Europe accounts for less than 0.1% of the world's seaweed cultivation. In the Baltic Sea Region, apart from the western waters on the border of the North Sea, only a few experimental farms are conducted. On a small commercial scale, the wild seaweed in the Baltic Sea is fished only in Estonia and Denmark (1.2.) There is little documented evidence of seaweed consumption prior to the 20th century in the Baltic Sea Region. In the 20th century, consumption of seaweed spread to the Eastern Baltic Sea, along with the Soviet cuisine, into which seaweed was introduced by the Korean diaspora. In the last 3 decades, there has been a sharp increase in interest in seaweed throughout the Baltic Sea Region, due to the growing popularity of Far Eastern cuisine, mainly Japanese (sushi). Currently, seaweed products are appearing more and more often on the market of the Baltic Sea Region - not only in Far East gastronomy, but also in the retail market (retail chains, specialist health food stores, less often - fish stores) - in the form of salads (loose and packed, in different flavors), dried products (including various snacks), as well as a number of innovative multi-ingredient products. There is also a wide availability of dietary supplements based on seaweed. Seaweed products are quite commonly known to consumers in the Baltic Sea Region - due to studies conducted during GRASS project, 26% of consumers in the Baltic Sea Region have already eaten seaweed, but only as an ingredient of sushi, while nearly every fourth (23%) consumer has already tried seaweed also in other forms (e.g. salads, soups, snacks). As many as 34% of consumers declare that they "could try to eat" seaweed food products. Over 30% of consumers in the region believe that seaweed is food with particularly high pro-health values. Combining this data with the great interest of consumers in the region in products with guaranteed local (regional) origin, it must be determined that seaweed food products have great market potential. Algae can constitute new sources of functional compounds for food chain but also could be useful in various industries, as valuable raw material for:

- cosmetics and cosmetology industry,
- medical and pharmaceutical industry,
- agriculture (fertilizers, bio-stimulants),
- biofuel production,
- many other industrial applications.

Figure 12: Baltic bladderwrack (Fucus vesiculosus)

Seaweed is a raw material that, due to its numerous properties, is very versatile. Thanks to its high nutritional value (a rich source of proteins, essential amino acids and vitamins necessary for the proper functioning of the body), algae are widely used in food production. A diet rich in algae meets the needs for protein, essential amino acids, minerals and vitamins. As they are a source of elements, e.g. fiber, magnesium, zinc, calcium, potassium, iron, fluorine, phosphorus and copper, as well as folic acid and omega 3 acid, vitamins A, B, C, D, E are more and more commonly used in supplements (supplements with algae are recommended for various dysfunctions, e.g. an ingredient supporting slimming) and functional food. Algae, rich in elements, are eagerly used in the production of cosmetics, because they stimulate the reconstruction and protection of the epidermis, soothe irritations, and also have anti-allergic and anti-inflammatory properties. They have a cleansing, moisturizing and soothing effect, making them suitable for the care of dehydrated, acne and hypersensitive skin. In the cosmetics industry, they are also used in the production of preparations that accelerate skin healing, regenerate and rejuvenate. Algae is also used in pharmacy and laboratories, and for the production of biomaterials. Due to their anti-inflammatory, antioxidant, antibacterial, anticancer and antioxidant properties, algae can be used in the treatment of many diseases in the world, because there is a growing interest in natural pharmaceuticals, which are perceived as safer for humans. Algae as a renewable energy source, also represent a huge potential in the production of biofuels, and the rapidly advancing technology development makes them increasingly used in other technical and industrial products. As macroalgae uptake naturally occurring nutrients, their cultivation sites may also provide environmental services - they can be used as a tool to combat eutrophication. The biogen content and the rate of their uptake vary between the macroalgae species and populations and depend on environmental conditions. Generally, growth rates and the nutrient uptake rates are higher in fast growing green macroalgae than slow-growing species like many red and brown seaweed. Based on the calculations, it is possible to remove 1.3-7.9 kg of nitrogen and 0.2-1.9 kg of phosphorus while harvesting 1 ton of Baltic macroalgae, depending on the species.

Figure 13: Furcellaria lumbricalis

The macroalgae species that, according to their properties, content of valuable substances or abundance can be considered suitable for cultivation in the Baltic Proper and adjacent basins are: (1) red alga *Furcellaria lumbricalis* - the only species that was harvested on a commercial scale in the Baltic Sea to obtain polysaccharide furcellaran (gelling agent); (2) red alga *Ceramium tenuicorne* - this small, filamentous species contain many bioactive substances, can be utilised to produce agar and is rich in red pigment phycoerythrin; (3) brown alga *Fucus vesiculosus* that has been used as food and medicine for centuries is commercially harvested in few countries outside the BSR to obtain its structural polysaccharide fucoidan and can be also used as a source of alginic acid; (4) *Ulva intestinalis* - green alga that is very abundant on rocky bottoms along the Baltic coasts is suitable for human consumption and cultivated in Japan. For the Western Baltic/ Sweden, characterised with higher salinity, two Laminariales species are suitable for cultivation - *Laminaria digitata* and *Saccharina latissima* and they are/ can be utilised as high value food products or in alginate industry. It should be emphasised that there are few different legal barriers but also opportunities for the cultivation and harvesting of macroalgae. The legal aspects can be divided to: (1) spatial conflicts and synergies with other users and maritime sectors resulting from Maritime Spatial Plans for BSR countries; (2) legal regulations directly related to the cultivation of marine organisms and resulting from the environmental law, usually connected to the necessity of obtaining few permissions from the relevant authorities; and (3) the regulations related to the usage of macroalgae as food and feed ingredients, connected mainly to the limits of harmful substances, food labeling and the introduction of novel species into the market. As *Sacchcarina latissima* and *Laminaria digitata* are experimentally and commercially cultivated in Sweden and Denmark, the cultivation techniques, based mainly on the long-line technology, dedicated for these species exist and are well described in the literature. The experience in cultivation of macroalgae in the Baltic Proper and adjacent basins is limited to few experimental initiatives. Based on the findings from these initiatives and on the scientific literature, we assumed that sufficient knowledge exists to plan at least experimental farms of *Fucus vesiculosus* and *Ulva intestinalis* in the Baltic Sea. Based on the results from FucoSan project, we propose fucus farms which rely on vegetative fragments of thalli as a 'seeding' material, placed in the experimental infrastructure consisting of floating baskets and cultivated throughout the year. For Ulva intestinalis we suggest the farm based on the long-line technique - using lines with planted spores, suspended shallow below the water's surface and located in the shallow coastal zone, most preferably in areas characterised with high nutrient concentration. Due to seasonality, it is possible to cultivate U. intestinalis 5-6 months per year.

Figure 14: Seaweed farm in Sweden courtesy of Nordic Sea Farm

Preliminary calculations show that the production of macroalgae in the south-east of the Baltic Sea: Poland, Latvia, Estonia is quite cost-intensive. Depending on the adopted input parameters, the production cost of 1 kg of fresh *Ulva* varies from 0.23 €/kg, with the optimistic assumption of efficiency of 87t/ha, up to 1.0 €/kg, assuming the pessimistic version of the yield of 9.8t / ha. The estimated unit cost of producing 1 kg of fresh Fucus is ca 2.34 €/kg. Starting the cultivation of seaweed in the Baltic Sea Region, from the market point of view, would be a response to the growing consumer demand for new, pro-health products of aquatic origin, also in line with the trend of reduced demand for animal products. Production in the Region would make it possible to offer a local, ultra-fresh product. From a socio-economic point of view, local cultivation of seaweed would contribute to increasing added value in the Region (replacing imported products), promoting employment (including people leaving sea fishing) and better utilizing the potential of fish processing plants. From an environmental point of view, the cultivation of seaweed, especially fast-growing seaweed (like U. intestinalis), offers a unique opportunity to reduce water eutrophication while accumulating CO_2. The main problems and threats to the start of macroalgae cultivation in the main part of the Baltic Sea (except its western part) are: the inability to estimate the market absorption capacity for new species, practically absent in the food market of the Region (such as U. intestinalis); lack of proven in practice technologies for the cultivation of *U. intestinalis* and *F. vesiculosus* in Baltic conditions; legal and legislative barriers - especially for first market entrants; finally - the lack of public funding for the water-environmental services that will be provided by seaweed farms. The following report synthetically collects the available knowledge about the production possibilities and the seaweed market in the Baltic Sea Region and was carried out as part of the GRASS project - Growing Algae Sustainably in the Baltic Sea.

4.2 Manual on the socioeconomic benefits, risks and opportunities of macroalgae production and use in the BSR

We can only talk about the socio-economic impact of the local seaweed industry on the Baltic Sea Region on the basis of the assumptions made regarding the scale of future seaweed cultivation. There is no such assumption in any official policy documents for the Baltic Sea Region. Therefore, we estimate the socio-economic impact in this fact- sheet based on an ambitious, proprietary strategic vision (described on page 3).

We show that the use of 3,480 ha of Baltic Sea waters for the cultivation of fast-growing seaweed such as *Ulva intenstinalis* can have significant positive environmental effects, such as significant nutrient reduction in the eutrophied waters of the Baltic Sea and significant accumulation of CO_2. At the same time, some negative impacts on the environment (seabed, landscape) are much smaller than the obtained benefits (see page 2).

The development of the consumption of seaweed, regardless of whether it is based on local production or – as at present – imported raw materials, has a positive effect on the health of the society. The versatile positive health benefits of seaweed have been scientifically proven. This is especially important in the face of the growing demand for vegan products (see page 4).
The development of the seaweed sector and at least partial replacement of imported raw materials with local production translates into the multiplication of the added value in the Region per unit of seaweed products used. At the same time, the project demonstrated that biorefining is the most comprehensive and future-proof option for processing seaweed raw materials (see page 5).

The development of local production of seaweed is an opportunity to use the human potential, especially the competences of fishermen leaving the Baltic fishery, as a result of the reduction in fishing opportunities every year (see page 6 of the full document).

There are a number of strong research centers dealing with seaweed in the Baltic Sea Region. However, there are few initiatives focused on practical implementation so far. Therefore the implementation of any ambitious plan should be preceded first by conducting experiments on a semi-industrial scale in the Baltic Proper, as the available literature data regarding the productivity of macroalgae such as *Ulva intestinalis* come from different years and show large divergences.

Conclusions

The production of seaweed biofuel in the context of reducing CO2 emissions is economically, energetically and technically challenging. In addition, any successful process appears to require both a method of preserving the seaweed for continuous feedstock availability and a method exploiting the entire biomass at commercial scale (Milledge and Harvey 2016). But the attractiveness of the seawed biorefinary concept is not based on the production of bioenergy itself but on integration of different biomass conversion processes to produce energy and value added product into a single facility. This in turn reduces the cost of fuel production with maximum utilization of the biomass (Balina et al. 2017).

Design of a biorefinery, which will generate sustainable food, fuels and chemicals with reduced CO2 emission is a complex task and is largely influenced by local raw material supplies, advances in multiple technologies and socio-economic conditions. A stepwise approach to maximizing the benefits from seaweed would include to sequentially extract high-value molecules used in the food, pharma or biotech industries, such as bioactive sulphated polysaccharides, pigments, and antioxidants and then convert—after extraction of carbohydrates for the hydrocollid industry or for biofuels production—the lower value residue to protein concentrates with value in the feed industry (Duarte et al. 2017).

Another dimension of seaweed cultivation is the use of the maritime space. Calculations of the area required for seaweed aquaculture to supply 60% of the transportation fuel vary broadly, from <1% of the economic exclusive zone (EEZ) for Norway, to 10% of the Dutch EEZ and about twice of the German EEZ (Fernand et al. 2017). In the case of Israel, achieving the national target reduction in greenhouse gas emissions (26% compared to 2005 emissions) by replacing fossil fuels by bioethanol would require as much as 71% of the national EEZ. (Chemodanov et al. 2017). The sea space is a limited resource for many countries. Its use for seaweed aquaculture may result in a change in CO2 emissions from other sources (e.g. related to the shipping). The estimation made by (Duarte et al. 2017)1 of CO2 emissions avoided per unit area by offshore wind farms (12,500 tons CO2 km2 year−1) compared with the potential CO2 sequestration intensity of seaweed farms (about 1,500 tons CO2 km2 year−1). However, seaweed can be planned in areas already occupied by wind farms and in areas where they are not possible to construct.

1 The CO2 emissions avoided per unit area by offshore wind farms were derived by dividing the CO2 avoidance of wind farms by the area occupied by the farms, corrected for a 2% lifecycle CO2 emissions over a nominal 20 year life span of the turbines (Martínez et al., 2009). The calculations were based on data for the Sandbanks offshore wind farms (Germany, 21 turbines in 61 km2)1 and for the LINCS offshore wind farms (UK, 83 turbines in 35 km2).

4.3.1 Handbook for public authorities

Figure 15: Seaweed farm copyright Gediminas Tamosaitis

The GRASS project has produced a number of capacity building materials targeted at public authorities, environmental regulators, business and the general public. This suite of resources can be referred to by practitioners and authorities alike to ascertain the legal, environmental and socio-economic considerations when approaching matters of governance and licensing of macroalgae farms or harvesting of beach cast in the future. The scientific nature of the reports and tools mean that the results can be relied upon as accurate sources of information and indicators for future environmental as well as market trends.

The handbook for public authorities is a guide through the main issues surrounding macroalgae cultivation and harvesting in the Baltic Sea. It covers the following topics:

1. Marine Spatial Planning synergies and conflicts
2. Technological platforms for cultivation, harvesting and storage of macroalgae in the BSR, spatial requirements and equipment
3. Skills
4. Funding and investment
5. Permits and licensing procedures
6. Political environment, regulations, and financial support
7. Product value chains, markets and stakeholders for blue bioeconomy and circular economy
8. Analyse benefits, risks and opportunities at a regional, national and at transnational level of the BSR of macroalgae cultivation, harvesting, and use, considering environmental, ecological, regulatory and socio-economic aspects

4.3.3 Training materials

The GRASS mini-documentary

The GRASS informational video is online and available to all under https://www.submariner-network.eu/grass with subtitles in all regional languages of the GRASS project.

Figure 16: The GRASS mini-documentary

Feedback from Stakeholder Events

Reports from the 18 stakeholder events can be found at https://submariner-network.eu/news-home

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