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AlgaePro BANOS

RECOMMENDATIONS FOR MONITORING OF SUSTAINABLE WILD HARVESTING OF MACROALGAE

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ABOUT THIS DOCUMENT

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LIST OF ABBREVIATIONS

Abbreviation	Description
BANOS	Baltic and North Sea
FAO	Food and Agricultural Organization
EU	European Union
UK	United Kingdom
EC	European Commission
NGO	Non-governmental Organization
WP	Work Package

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1. SUMMARY

Macroalgae are essential components of marine ecosystems. They offer a wide array of essential ecosystem services - significant contributions to global primary production and the efficient absorption of dissolved nutrients from their surroundings. Macroalgae (or seaweeds) play a vital role in coastal protection against erosive forces of wave action and contribute to carbon sequestration. Seaweeds also serve as keystone species that shape habitats in coastal ecosystems. Currently in Europe the utilization of algae is increasing in various commercial sectors. Majority of global macroalgal biomass is derived from cultivation, with an annual production of around 31 million metric tonnes (wet weight). Wild harvesting contributes approximately 1.2 million metric tonnes. In Europe the wild harvesting is providing approx. 0.25 million metric tonnes, accounting for approximately 98% of biomass production.

Macroalgal harvesting presents significant sustainability challenges, particularly as the demand for these resources grows in various industries. While the EU legal instruments emphasize the need for all human activities to be sustainable, there remains a notable gap in knowledge and regulation concerning the sustainable practices of macroalgal harvesting. The report seeks to address this gap by offering recommendations for harmonized monitoring and management approaches, ensuring that macroalgal harvesting (including beach cast collection) aligns with the EU's sustainability goals and contributes positively to the broader environmental objectives outlined in the Green Deal and related policies.

Several factors are relevant to ensure sustainability of seaweed wild harvesting, in all marine areas, when planning the harvest time and size: geographical distribution of species, various life histories of macroalgae species, recovery potential of each species, scale of created ecological impacts due to seaweed removal, as the level of impact correlates with intensity and frequency of harvesting. Collection of beach cast in most cases should also follow the principles of sustainability, as beach cast serves as part of coastal food webs, except for eutrophic or polluted areas where complete removal could be advised due to leakage of nutrients and pollutants.

Sustainability aspects of seaweed harvesting are included in national regulations of the countries where seaweed is regarded as a valuable resource, mostly on the Atlantic coast (France, UK, Norway). In the Baltic Sea area Estonia is the only country where wild harvesting of industrial size is allowed. Harvesting management systems are founded on a licensing process and involve collaboration between national authorities and fisher organizations, research institutions, and the industry.

Accurate estimates of the seaweed standing stock are prior to any monitoring of wild harvesting and evaluating its sustainability. Monitoring parameters applicable in most cases include characteristics of algae community and basic environmental indices. In the case of beach cast monitoring, concentrations of pollutants are recommended to follow, if the beach cast is intended for use as agricultural fertilizer. Screening for pathogenic microorganisms is suggested in beach cast accumulation areas during the active recreational season.

National policy support could include establishing a link between wild harvesting sites and national MSPs, share a governance of local seaweed resources and try new forms of cooperation for monitoring of harvesting. Joint projects and cost sharing can also reduce the costs of monitoring.

The EU Member States are invited to fill the knowledge gaps on impacts of seaweed wild harvesting and on estimates of beach cast amounts. However, in the future macroalgal cultivation seems more feasible and promising than wild harvesting due to vulnerable habitats of wild seaweed, experiencing stress under projected climate change. Therefore, further investigations focusing on long-term sustainability aspects of large-scale cultivation are of utmost importance.

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2. INTRODUCTION

Algae are essential components of marine ecosystems. They offer a wide array of essential ecosystem services, including significant contributions to global primary production and the efficient absorption of dissolved nutrients from their surroundings. Furthermore, macroalgae, commonly known as seaweeds, play a vital role in coastal protection against erosive forces of wave action and contribute to carbon sequestration (Christie et al., 2009; Teagle et al., 2017; Camarena-Gómez et al., 2022). Seaweeds also serve as keystone species that shape habitats in coastal ecosystems. Conversely, microalgae, acting as phytoplankton, form the foundational link in the marine and aquatic food chain. Given these widely acknowledged ecosystem services, micro- and macroalgae are prominently featured in numerous legal and strategic documents, both within the EU and globally. These organisms are recognized for their critical roles in biodiversity conservation, climate change mitigation, and sustainable development, making them integral to policies such as the EU Biodiversity Strategy, and the Marine Strategy Framework Directive. The utilization of algae is increasing in various commercial sectors. Approximately 61% of European companies involved in seaweed biomass production focus on the food and food-related industries. The largest fraction of the biomass is used for producing hydrocolloids (such as alginates and agar), though the majority of the financial revenue comes from companies directly producing seaweed for food, accounting for 36%. A notable portion of the biomass also goes toward the cosmetics and well-being sectors, making up 17%, while fertilizers and biostimulants represent less than 11% of the total market share across Europe (Araújo et al., 2021).

Globally, the majority of macroalgal biomass is currently derived from cultivation, with an annual production of around 31 million metric tonnes (wet weight). In contrast, wild harvesting contributes approximately 1.2 million metric tonnes. Macroalgal cultivation is led by Asian countries, notably China and Indonesia, which collectively represent 99% of the world's cultivated output. Wild harvesting has traditionally been more scattered across the globe, with Chile, China, and Norway emerging as the top three countries in terms of harvesting naturally grown seaweed (FAO, 2018; Camarena-Gómez et al., 2022). In Europe, wild harvesting has remained stable over the last 20 years providing approx. 0.25 million metric tonnes (wet weight), while the cultivated part of macroalgae constitutes 0.0007 million metric tonnes (data of 2014-2016, JRC, 2019). As a result, wild-harvested macroalgae account for approximately 98% of biomass production and is considered the most crucial raw material for the seaweed industry in Europe.

Macroalgal harvesting presents significant sustainability challenges, particularly as the demand for these resources grows in various industries (Vincent et al., 2020). While the European Green Deal and other EU legal instruments emphasize the need for all human activities to be sustainable, there remains a notable gap in knowledge and regulation concerning the sustainable practices of macroalgal harvesting. Although seaweeds have been harvested since ancient times, in the face of growing commercial interests and pressures it is important that specific management tools are developed and implemented to help maintain the health and integrity of not only seaweeds, but of all related resources. Recently, several studies and reports have addressed the sustainability of wild harvesting approaches in European sea basins (MacMonagail et al., 2017, Wilding et al., 2021, GRASS project reports 2021). To promote the sustainable development of this activity and identify its limitations, it is crucial to present a thorough overview of current macroalgal harvesting practices. The current task seeks to address this gap by offering recommendations for harmonized monitoring and management approaches, ensuring that macroalgal harvesting aligns with the EU's sustainability goals and contributes positively to the broader environmental objectives outlined in the Green Deal and related policies.

3. METHODOLOGY

Our task was to characterize the practical approaches used for monitoring the collection of seaweed from the sea or beach for subsequent industrial processing. Therefore, our focus has been on several key species relevant to wild harvesting in marine and tidal areas. Despite the limited data on harvesting in the United Kingdom, insights from

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this region have proven invaluable due to the extensive descriptions and reviews of best practices and procedures available. We have included also the information from Norway, as wild harvests of the country constitute more than 60% of European seaweed biomass.

3.1. Literature review

For the compilation of the review, we used resources retrieved by Google Scholar when applying the following sets of search parameters: *algae species name, country*, and *type of harvesting*. The list of species included those directly relevant for the project partners, but also those relevant to the BANOS area and beyond, to embrace the scope of investigations and results. We also checked the EMODnet database on Human activities/Aquaculture/Macroalgae to see whether all relevant countries have been included in our search. The approach is summarized in *Table 1*. Information and knowledge on beach cast was searched without including countries, using keywords *storm cast, beach cast, beach wrack, gathering, collecting, and harvesting*.

Table 1. Searched keywords (in combinations) for literature review

Algae species	COUNTRY	Type of harvesting
Ascophyllum nodosum	Ireland, Canada, Norway, France	Manual, mechanical
Chondrus crispus	Ireland, United Kingdom	Manual
Saccharina latissima	France, Ireland, Norway, United Kingdom	Manual, mechanical
Laminaria digitata	France	Mechanical
Laminaria hyperborea	Norway, France	Mechanical
Furcellaria lumbricalis	Estonia	Mechanical
Fucus vesiculosus/Fucus spp.	Denmark, France, Ireland, Norway, United Kingdom	Manual
Ulva spp.	France, Ireland, Norway, United Kingdom	Manual
Porphyra umbilicalis	France, UK	Manual
Palmaria palmata	France, Ireland, Norway, United Kingdom	Manual

3.2. Survey of monitoring practices

3.2.1. European Union framing

At the European Union-level relevant environmental policies, directives and regulations were checked. The scope included the use of the marine space, observation of good environmental status, protection of species and habitats, and sustainable aquaculture guidelines. We did not address the safety of food and feed, or novel food aspects as these represent stages of seaweed processing. Still, we considered the joint Marine Stewardship Council (MSC) and the Aquaculture Stewardship Council (ASC) standards for the certification of seaweed operations that should ensure the sustainable and responsible exploitation of seaweed resources. The list of documents is included in *Table 2*.

Table 2. EU and international documents included in the survey

Document title	Topic
EC Algae Initiative	Development of sustainable algae industry in EU
Marine Spatial Planning Directive 2014/89/EU	Marine space use
Marine Strategy Framework Directive 2008/56/EU	Good ecological status in EU marine areas
Water Framework Directive 2000/60/EU	Good environmental status in EU waters
Habitats Directive 92/43/EEC	Protection of EU habitats
Environmental Impact Assessment Directive 2011/92/EU	Principles for environmental impact assessments in EU
Organic Food Regulation 2018/848/EU	Includes also organic seaweed collection
Strategic guidelines for a more sustainable and competitive EU aquaculture for the period 2021 to 2030	Development of sustainable aquaculture in EU
MSC/ASC Standard	Sustainable operations and procedures for seaweed resources

3.2.2. National practices

For an overview of national monitoring practices the results of previous international projects tackling these issues were first scanned. We checked project reports of the last ten years, i.e. 2013 - 2023/2024, as the regulations could have changed due to stock dynamics of seaweed. The projects included NetAlgae, CONTRA, GRASS, EU4Algae, Blue Platform, BalticSeaSafe, and ESMIC.

To gain a detailed understanding of monitoring practices, we conducted interviews with two project partners—one from Estonia and one from Germany—focusing on the procedures implemented in their respective countries. Estonia is the only country in the Baltic Sea region where the red macroalgae *Furcellaria lumbricalis* has been harvested annually and sustainably for more than 20 years. There are no options for the wild harvest of *Fucus* in Germany due to current regulations, but experience is obtained in Denmark. Wild harvesting in Denmark is regulated according to purpose of collection and location of the site. The University of Tartu and the company oceanBASIS GmbH, as project partners, supplied details regarding the monitoring framework, relevant legislation, and methodology.

4. WILD HARVESTING AND BEACH COLLECTION OF MACROALGAE

'Wild' harvesting of seaweed resources is generally done by the selective cutting from monospecific stands of seaweed (e.g. rockweeds and kelps) or alternatively, by collecting storm-cast fronds (Monagail et al., 2017). Collection of seaweed biomass from the sea or coast remains the predominant method for macroalgae production in Europe, a practice largely consistent over the past two decades. Approximately 68% of macroalgae production units in 11 European countries rely on this method, with 85% of them employing manual harvesting (Fig.1.). Mechanical harvesting, used by only 15% of units, has substantial biomass removal potential due to the use of vessel fleets (Araújo et al., 2021).

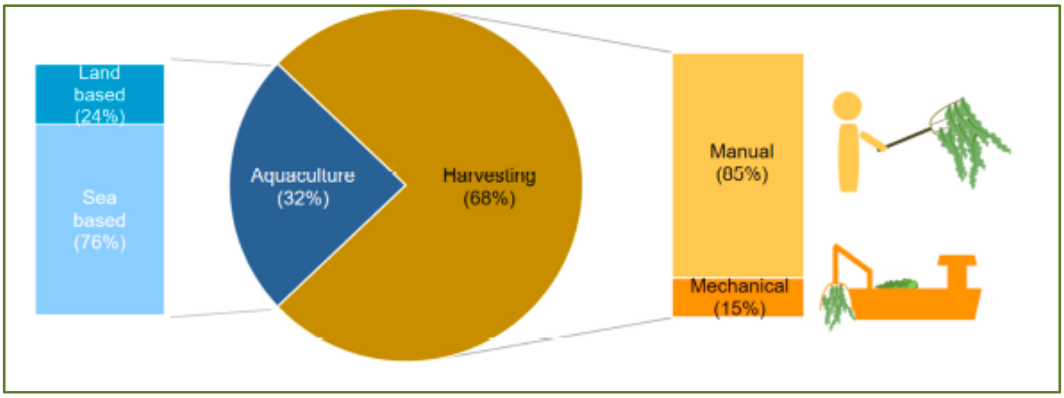

Figure 1. Macroalgae production methods in Europe (share by the number of companies using these methods), modified from Araújo et al., 2021

4.1. Wild harvesting techniques

As with nearly all natural resources, we differentiate between manual and mechanical methods of harvesting. In the case of seaweed, the division between those became quite late, about 60 years ago when harvesting of kelps became mechanized in Norway in the late 1960s (Vea & Ask, 2011).

4.1.1. Manual harvesting

Manual harvesting is the oldest method of seaweed collection, practised for several centuries. Historical records indicate that laws governing seaweed collection in Iceland, Brittany, and Ireland date back to the 10th century AD when seaweed was widely used as animal fodder, soil enrichment and for stabilizing land in northwest Europe (Angus, 2017; Buckley et al., 2023). At present, hand harvesting in Europe is mainly for personal consumption or use, rather than on an industrial scale. Ireland is the only exception where e.g. *Ascophyllum nodosum* accounts for approximately 95% of total Irish seaweed landings and most of it is manually harvested. In the UK, manual harvesting is widespread both for commercial and personal (recreational) purposes, although no precise data records exist (Wilding et al., 2021a). **Hand cutting or picking** involves harvesting living species by hand at low tide using tools such as serrated sickles or scythes. Subsequently, the harvested seaweed is loaded onto a (wooden) boat and towed to the nearest harbour. Depending on their experience and skills, seaweed harvesters are typically capable of cutting between 1 and 4 tonnes in a single tide cycle (Monagail & Morrison, 2020), although it has been known for some cutters to harvest as much as 7 tonnes on a good tide. In the UK, hand harvesting methods usually involve selective cutting of the frond with scissors or a small knife, although some harvesters (presumably more recreational than commercial) are thought to pluck seaweeds by hand. Access by foot from the shore is most common, with a small number of commercial operators using diving or free diving methods for species found lower on the shore (Wilding et al., 2021a).

4.1.2. Mechanical harvesting

Mechanical harvesting has been widely used in Northern Atlantic countries since the middle of the 20th century. In Europe, mechanical harvesting is currently carried out by boats, mainly in Norway (Rogaland to Sør-Trøndelag), France (Brittany and Normandy), Estonia and, to a lesser extent, the Basque Country (Spain) and Ireland. The development of the mechanization of seaweed harvesting occurred in the mid-1970s in France and Norway in response to the increasing demand for raw material for the alginate extraction industry (Mesnildrey et al., 2012). If we exclude the means of harvest transportation (like tractors or other vehicles), then the two most common methods currently used are **trawling/sledging/dredging** or mechanical **'hedge' cutting.** In the case of species inhabiting larger depths, like kelps, trawling is used with a device which tears living plants larger than a certain size from the substrate and leaves smaller plants for re-growth (i.e. generally only mature plants are harvested). Existing devices include the Norwegian kelp dredge designed to harvest *Laminaria hyperborea* (Fig.2) and the Scoubidou trawl in France, which uproots *Saccharina latissima* using a crochet-hook-like implement (Wilding et al., 2021b). These devices operate in areas of rocky substrate and therefore differ from other forms of dredging (e.g. scallop dredging) that physically disturb the underlying substrate. However, there may be some potential for physical disturbance of the substrate by other devices, such as dredgers used in maerl extraction. The **mechanical 'hedge' cutting** method involves mechanical seaweed harvesters - specialized vessels that work close to the shore and cut the living seaweed as the stalks float above the seabed. The most prominent example is the Norwegian suction/cutter harvester which was designed to harvest *Ascophyllum nodosum*. Due to its unsustainable use in Canada in the 1980s and 1990s, mechanical harvesting has since been banned and *A. nodosum* is harvested by hand with a rake from a boat (Chopin & Ugarte, 2006).

Figure 2. Norwegian kelp harvester in operation, source Vea & Ask, 2011.

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4.2. Beach cast harvesting

Beach cast harvesting methods include hand gathering, which involves collecting beach-cast species from the strandline by hand, and mechanical gathering methods which involve collecting beach-cast species from the strandline using tractors. The materials used for gathering beach cast weed are various, and may include a variety of hand rakes, forks and spades, buckets, bags, wheelbarrows or handcarts, nets, horses, and larger vehicles used for transport (Mac Monagail et al., 2017). Removal using vehicles including tractors, bulldozers and lorries is common (Wilding et al., 2021a).

The beach cast or beach wrack displays a lot of variation across Europe. While in Ireland, the UK, and France, beach wrack is a resource for harvesting and further processing or consumption, in the Baltic Sea countries it is mostly seen as a nuisance except for Estonia, particularly in its western regions, where beach cast composed of the red alga *Furcellaria lumbricalis* is commercially harvested for furcellaran production. Not surprisingly, the approach is highly related to the species composition of the beach cast. In the Baltic Sea, beach cast seaweed often contains a high proportion of annual green and brown algae, not regarded as valuable for processing. Still, several examples exist when also beach cast harvest is receiving special attention. In Solrød Municipality, Denmark, several technologies for the mechanical collection of beach cast have been tested whether the seaweed can be used as a source for biogas. The mechanical units include an excavator with a very big shovel on the front that can remove cast seaweed from both the beach and the shoreline, a beach cleaning machine which mostly operates on the beach, a loader tractor harvesting seaweed straight from the shore and the shoreline, and a large metal rake attached to a tractor, which works best on the beach (Lybæk & Kjær, 2023, Fig. 3). On the island of Gotland, Sweden, tractors are used to collect seaweed and the piles are used to make compost (Nathaniel et al., 2024).

Figure 3. Beach cleaning machine (left panel) and loader tractor collecting beach cast in water (right panel) in Denmark, source Lybæk & Kjær, 2023.

4.3. Factors impacting the sustainability of wild harvesting

Like all human activities in the sea, wild harvesting is no exception in having an impact on species populations themselves, ecosystem functioning, habitat quality and wave regimes at the coast. Several warning examples exist from e.g. overharvesting of *Ascophyllum nodosum* in Canada (Monagail et al., 2017) or *Gracilaria* and *Hypnea* species in Brazil (Rebours et al., 2014). Therefore, for the sustainability of wild seaweed stocks, several requirements should be followed, both for manual and mechanical harvesting.

In recent reviews on manual and mechanical harvesting of more than 20 macroalgal species, Wilding and co-authors (2021a & 2021b) provide a comprehensive list of factors impacting the sustainability of these activities. The concepts are applicable for all the seas and algal species, and therefore listed below.

Geographical distribution
Species at the range edge are likely to experience a range of environmental stresses that may reduce their growth rate and post-harvest recovery. For example, increasing sea temperature was found to have the largest negative impact on yields of *Laminaria hyperborea* in Brittany, France, where the species is close to its southernmost range edge (Werner & Kraan 2004). This should be considered when planning a production from the harvest. Climate change with warming seas will also affect the borders of the range. A decline in cold-water species such as *Laminaria digitata* and *L. hyperborea* can be expected. On the other hand, the distribution range in the north is expected to expand.

Species specific approach
Seaweeds have various life histories, ranging from short-lived ones like *Ulva* spp. to species reaching several years or even decades old such as *Ascophyllum* and kelps. *Ulva* spp. can reach maturity in a matter of weeks, which along with its high reproductive output and dispersal capacity allows it to rapidly recover or colonize new areas. Laminarian kelps and *Ascophyllum nodosum* are mature after several years and individual fronds may live for up to 20 years (Wilding et al., 2021a and references therein). These different life histories have clear implications for post-harvest recovery. Also, reproduction and dispersal features should be considered when harvesting. The dispersal of seaweed spores is of vital importance to post-disturbance recruitment and recovery. The dispersal capability of seaweed spores will depend on the species, release depth (based on where the fruiting bodies are on the plant), season, and local hydrodynamic conditions. The variety of dispersal distances and successful recruitment varies between a few metres (*Chondrus crispus*) to an estimated 35 metres (*Ulva* spp.). All species, though, have some microscopic life stages, potentially allowing for recovery from an invisible "seed bank".

Recovery potential
Recovery from harvesting is influenced by the proportion of the plant being removed, harvesting intensity, frequency and proportion of standing stock biomass harvested. Understanding the differences in growth and recovery rates between species is key to developing species-specific management plans. Most seaweed species demonstrate seasonal growth, so harvesting season will impact recovery, with faster recovery expected during times of peak growth. However, periods of peak growth, reproduction and recruitment vary greatly between species. Norwegian studies of kelp recovery following mechanical harvesting have demonstrated high site-level variability, with populations recovering in approximately 4 years at one site and >6 years at another. Growth rates of Norwegian *L. hyperborea* are higher in wave exposed locations, therefore, harvested kelp can recover more rapidly in wave exposed locations than in sheltered locations. It is evident that local environmental conditions mediate recovery and promote site-level variability.

Ecological impacts
The removal of seaweeds from the ecosystem creates several ecological impacts. The level of impact will depend on the intensity of harvesting, the spatial scale and the frequency of harvesting events which will also influence the recovery rate. Overall, harvesting will reduce the contribution of targeted seaweeds to ecosystem processes and functions. Harvesting can affect the population structure of some species, reducing their reproductive capacity. Taking the seaweeds out of water also affects the attached fauna causing by-catch of non-target species, therefore processing close to the shore would increase the chances of survival for these non-target species. Primary and secondary production are impacted, as well as related food webs. Since seaweeds are key to forming nursery and shelter habitats for invertebrates and fish, large-scale removals can significantly disrupt and negatively impact ecosystem components. Removal of native species can provide a ground of colonization for non-native or opportunistic species with different biological features, e.g. extensive growth and reduced value for habitats.

Aspects of beach cast collection
In many cases, beach-cast algae provide an essential food source for beach invertebrates and have been shown to play a vital role in coastal food webs. An example from Scotland shows that the biomass of fly larvae found in mounds of rotting seaweed (kelp) are some of the highest reported globally, and these larvae are a critical food source for shorebirds that stop-over on the islands to 'refuel' during their spring and autumn migrations (Orr 2013). Removal of beach cast can also affect nutrient flows - when decaying nutrients from the seaweeds are re-mineralized and exported back to the sea. If this recycling is missing, the coastal ecosystems will not have the same

capacity of primary production both for phytoplankton and macroalgae. In contrast, in eutrophic ecosystems like the Baltic Sea, where the overgrowth of opportunistic filamentous algae occurs, beach cast formed from these algae can disrupt important habitats and species, leading to substantial negative effects. In such situations, removing the beach cast is considered advantageous for the coastal ecosystem. Moreover, the removal of excess nutrients from the coastal area helps reduce the adverse effects of eutrophication.

The decomposition of seagrass wrack contributes to carbon emissions, with global CO_2-C flux from this process estimated to range between 1.31 and 19.04 Tg C per year. This is comparable to the annual emissions produced by 0.5 to 9 million people, depending on their location. Consequently, removal and use of such wrack for agricultural soil improvement or converting it into a marketable product presents an opportunity to have a positive impact on carbon sink efficiency, particularly as climate change and coastal development continue to accelerate (GRASS factsheet, 2021). However, this is only true if the removal is done sustainably. Otherwise, the removal of wrack could have negative ecological impacts on other coastal habitats (Hyndes et al., 2022).

On the other hand, evidence exists on beach cast containing high volumes of pathogenic bacteria, especially close to river outflow areas (Kalvaitiene et al., 2024 and references therein). During the decay process, changes both in bacterial consortia and physicochemical conditions occur, which might favour potential pathogens. In the study from the Baltic Sea, human and bird related faecal pollution has been identified in the beach cast accumulations. Another factor is the accumulation of heavy metals in beach cast with a following release using the same mechanism as for nutrients (Greger et al., 2007; Franzen et al., 2019; Almqvist et al., 2021).

Thus, the sustainable and safe harvesting of beach cast requires a similar level of attention as to that of fresh algae, especially in the areas with less favourable environmental quality like in the Baltic Sea.

5. POLICY AND REGULATORY DOCUMENTS ON WILD HARVESTING AND BEACHED SEAWEED COLLECTION

5.1. European Union documents

Attention to seaweed in European Union documents has notably increased over the last 10 years. Previously, seaweeds were primarily recognized as a habitat-forming group at the EU level and were considered mainly in environmental protection documents. Even now, the number of documents addressing macroalgae remains limited, with most focusing on seaweed cultivation as part of aquaculture. Wild harvesting and beach cast collection have received minimal attention so far, as these activities are largely regulated by individual countries.

5.1.1. Planning documents

The EC’s Algae Initiative is the most prominent policy planning document addressing algae as a resource and considering the sustainability of its use. The central idea of the document is to promote the development of the algal industry in Europe, and the fragmented regulatory framework is mentioned as one of the obstacles (Fig. 4).

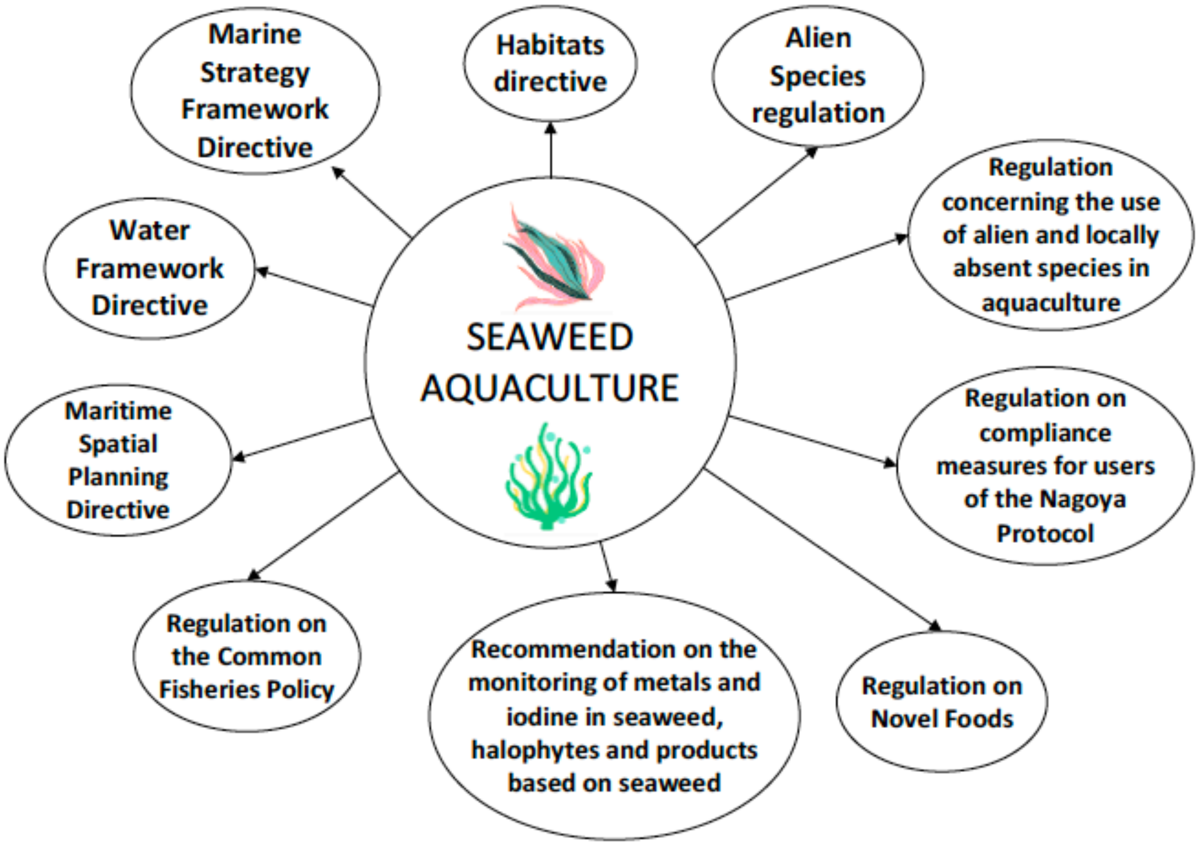

Figure 4. Legal acts of the EU relevant for seaweed aquaculture, source EC Algae Initiative, 2022.

Among the proposed actions, the European Commission also encourages Member States to simplify national licensing procedures and governance for algal cultivation. The Algae Initiative highlights the need for better knowledge of the impacts of wild harvesting and the quantity of beached seaweeds to determine whether sustainable business opportunities are feasible. Studies on national monitoring schemes for wild harvesting and beach cast collection are planned, with the expectation that Union-wide recommendations will likely be based on best practices from national case studies.

5.1.2. Regulatory documents

At the time of the report writing, the Organic Food Regulation 2018/848/EU is the only document having specific rules for the cultivation of organic algae and also covering wild harvesting (collecting the 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 significantly affect the stability of the natural ecosystem or the maintenance of the species in the collection area. Furthermore, the amounts collected do not have a significant impact on the state of the aquatic environment.

As already mentioned before, the main legislative acts related to, *inter alia*, wild harvesting of seaweed and beach cast gathering are the Habitats Directive 92/43/EEC, 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 Regulations 1143/2014/EU and 708/2007/EC, and the Environmental Impact Assessment Directive 2011/92/EU.

5.2. National documents and practices

In EU countries, the substantive criteria for environmental protection are established by EU legislation, which is then incorporated into national laws. Monitoring requirements are typically included as part of the permit. Environmental permit systems are managed at the national or regional level, meaning permits are issued by government authorities within these jurisdictions. The purpose of environmental permitting for specific activities is to minimize environmental risks, prevent and reduce pollution, and ensure that no significant harm is inflicted on the environment. The permitting system incorporates environmental impact assessments (EIA) and public participation. The EU's Environmental Impact Assessment Directive requires an EIA for major projects and recommends it on a case-by-case basis for other projects that may have direct or indirect effects on environmental factors, including human health, biodiversity, land, soil, water, air, climate, landscape, material assets, and cultural heritage. An environmental impact assessment must be conducted before issuing permits for projects likely to cause significant environmental harm. Public involvement, including the participation of local residents and NGOs through written statements and public hearings, is a crucial component of the EIA process (Albrecht et al., 2023).

The environmental permit in the best case should be issued in accordance with the national Maritime Spatial Plan, but the practices differ according to the importance of seaweed as a resource in a country's economy. In most of the Baltic Sea countries where wild harvesting of living seaweed populations is prohibited, the MSPs do not have any designated areas for this purpose. **Estonia** is one of the exceptions, and their national practice is described in Chapter 5.2.1.

In **Denmark**, the gathering of seaweed for private consumption or sale is allowed since there is no law prohibiting this raw material reclamation. When this gathering/harvest of natural populations occurs, and is for commercial purposes, the regulations for seaweed manufacturing need to be respected. In this case, a company needs to perform a risk assessment of the activity, assessing the water area where the seaweed is being harvested from the natural populations or cultivated, evaluating the species and composition and how to handle the seaweed, and the company has the responsibility to comply with the relevant regulations. There is no demand for routine sampling and analysis regarding the use of seaweed for food, but the food products (or as supplements) should comply with the respective regulations (Camarena-Gómez & Lähteenmäki-Uutela, 2021).

In **France**, for example, seaweed harvesting is managed by the administration with fishers' organizations. Seaweed gathering onshore or at sea is regulated at the national and regional levels. National regulations must be applied everywhere, but considering that most seaweed produced comes from Brittany, specific regulations are made at the regional scale and even at the local scale. The following items are regulated: environmental protection policies by areas, licence fees, number of licences, periods of harvest, restricted areas, quotas and specific conditions during the campaign. Each relevant species is considered, indicating allowed way of collection, allowed minimal size for collection, period of harvest, and quotas (Mesnildrey et al., 2012).

On the Island of Gotland, **Sweden**, in the case of beach cast collection it is supported by the national marine policy scheme LOVA to reduce eutrophication in the Baltic Sea. Local organizations that receive LOVA funding for the harvesting of beach wrack are required to submit a final report to the County Administrative Board once the project has been completed. The final report must include estimates of the amount of nitrogen and phosphorus that was recirculated (from sea to land) because of the project. In addition, projects engaged in the harvesting of beach wrack are encouraged to take samples of the biomass and send them in for chemical analysis. Biomass is analyzed for dry matter, nitrogen, carbon, carbon/nitrogen phosphorus, potassium, magnesium, calcium, sodium, sulfur, copper, iron, manganese, zinc, and cadmium (Nathaniel et al., 2024).

Although in parts of the UK like **Wales** and **England** wild harvesting is not strictly regulated, sustainability is considered in the Codes of Conduct for the present situation and assuming that the intensity of manual harvesting may increase in the country. Wilding et al. (2021a) describes the necessary management approaches for sustainable wild harvesting and emphasizes a combination of management methods as the most effective ones. The following manual harvesting methods are recommended:
- observe cutting height, leave a proportion of the plant (holdfast and some frond) remaining at the base;

- selectively cut with scissors rather than plucking or uprooting to support recovery and reduce by-catch;
- avoid by-catch of epiphytes and vulnerable species;
- avoid harvesting reproductive material if possible (or only take half from each plant);
- for certain species (e.g. for *Fucus serratus* and *F. vesiculosus*), only harvest part of mature plants.

Regarding the harvesting period, it is recommended to harvest during the active growing season and avoid harvesting during the reproductive season. The frequency of harvesting should include fallow periods to allow the canopy of *Ascophyllum nodosum* and perennial kelp to recover. Harvest limits should be set as quotas, volumes or bag limits, and the proportion of standing stock biomass removed/left remaining should be followed. Harvesting spatial considerations include sparse harvesting, leaving unharvested plants between those taken. No-take protected areas are also suggested including those designated by existing legislation. Those can serve as a reference area, to protect a source population, or maintain ecosystem services such as biodiversity or coastal protection. Spatial, temporal and seasonal closures should be considered when stock declines, during peak seaweed reproductive times, seasons of slow growth, or during breeding/nursery periods for associated marine life. However, it is stressed that currently baseline information is missing to allow routine monitoring of wild resources to inform effective management. Monitoring of ecological baselines, such as the available standing stock biomass, and reporting of harvested quantities will be required to quantify the spatial and temporal extent of harvesting activities (Benion et al., 2019).

In **Norway** sustainable harvesting of *Laminaria hyperborea* has been established by well-planned and followed management and monitoring schemes. Based on good knowledge of *L. hyperborea* ecology and biology, and organized in close cooperation between researchers, national authorities and industry, the seaweed management plan was developed (Vea & Ask, 2011). The principles of the plan include: 1) the organization of harvesting in a revolving 5-year (four in certain areas) cycle to secure the regrowth of kelps, 2) a control of the regrowth is in place as a part of the annual programme of the Institute of Marine Research since 2004, 3) a commercial control of the harvesting areas to assure they are fully utilized during the year, and the target volume for that area is harvested. Areas protected from storms can be harvested in the fall/winter while more exposed areas can be harvested in the calmer spring and summer.

Below we provide two case examples of wild harvesting in the project area for industrial purposes.

5.2.1. The case of Estonia

In Estonia, various sustainable development acts and strategies have been adopted (Republic of Estonia, 2016). The Estonian Parliament (Riigikogu) enacted the Sustainable Development Act in 1995 and introduced the "Sustainable Estonia 21" strategy in 2005. This strategy addressed three of the key goals among the 17 global Sustainable Development Goals set by the United Nations: increasing welfare, fostering a cohesive society, and maintaining ecological balance. In 2020, the Estonian Government approved a new long-term national development strategy, "Estonia 35," which aligns with the global Sustainable Development Goals. Additionally, the Government has endorsed the Development Plan for Agriculture and Fisheries until 2030. This plan aims to promote sustainable development in sectors such as fisheries and aquaculture while preserving the environmental integrity of terrestrial and aquatic ecosystems. It also provides guidelines for developing fisheries policy to ensure an economically viable industry within a healthy marine environment. Aquaculture is among the marine sectors addressed in the new Estonian Maritime Spatial Plan (Camarena-Gómez et al. 2022 and references therein).

Currently, the only type of red macroalgae harvested in the Baltic Sea is *Furcellaria lumbricalis* (Weinberger et.al., 2020). It has attached and unattached (loose-lying/aegagropila) thallus forms, which represent two distinctive ecotypes (Martin et al., 2006). Within commercial scale, the loose-lying form of *F. lumbricalis* together with *Coccotylus truncatus* (Fig. 5) is trawled from the seabed in the Väinameri region - the sea area surrounded by the mainland on one side and the islands of Muhu, Vormsi, Saaremaa and Hiiumaa on the other sides. It is also collected from beaches in the form of beach cast.

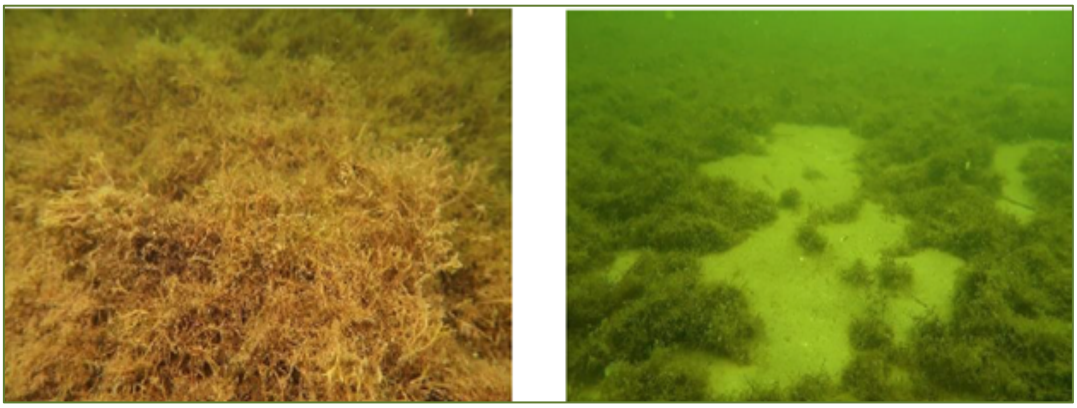

Figure 5. Unattached *F. lumbricalis* and *C.truncates* algae assemblage in Kassari Bay (sources: Kersen, 2014; Pajusalu et al., 2019; Palme & Herkül, 2023)

F. lumbricalis is the only aquatic "plant" currently regulated under the Fishing Act (Kalapüügiseadus 2015), last amended in 2021 (Estonian Government, 2021). The Act outlines specific rules for the areas and frequency of *F. lumbricalis* harvesting. While the seaweed in the sea is owned by the state, once it is washed ashore, it becomes the property of the landowner whose property is adjacent to the shoreline. A commercial fishing permit is required to harvest the loose form of *F. lumbricalis*, which is issued for a maximum of one calendar year, with the possibility of renewal. However, no licence is required for collecting beach-cast seaweed; however, the integrity of coastal nature must be respected. The total mass of red seaweed in Kassari Bay is estimated at around 200,000 tonnes, with an annual harvest quota set at 2,000 tonnes (approximately 1%). The permit specifies the harvesting area and gear, allowing harvesters to operate in one location per year, with that area left unharvested the following year. In recent years, however, the biomass of *F. lumbricalis* has declined, with an estimated 131,000 tonnes reported for 2023 (Paalme & Herkül, 2023), which is likely due to recent climate change phenomena (Paljusalu et al., 2020, 2023). All harvesting activities must be reported to the Agriculture and Food Board (Põllumajanduse ja Toiduamet) under the Ministry of Regional Affairs and Agriculture (Regionaal- ja Põllumajandusministeerium), the authority responsible for granting seaweed harvesting permits.

Over the past 30 years, permits have been held by only a few companies, and new applications are not permitted to preserve natural stocks (Camarena-Gómez et.al., 2022).

Red algae intended for use as industrial raw material should have a minimum agar content of 70% (wet weight). Additionally, the criteria for determining areas suitable for algal harvesting include an average agar biomass typically exceeding 1000 g/m² and a total community cover of 100% (or at least ≥95% if the agar fraction and biomass are particularly high) (Paalme & Herkül, 2023). However, the biomass collected in Estonia is relatively low: in total, during the last five years, 60 - 380 tonnes of red macroalgae (*Furcellaria lumbricalis* and *Coccotylus truncatus*) have been harvested in Estonian waters (Fig.6.).

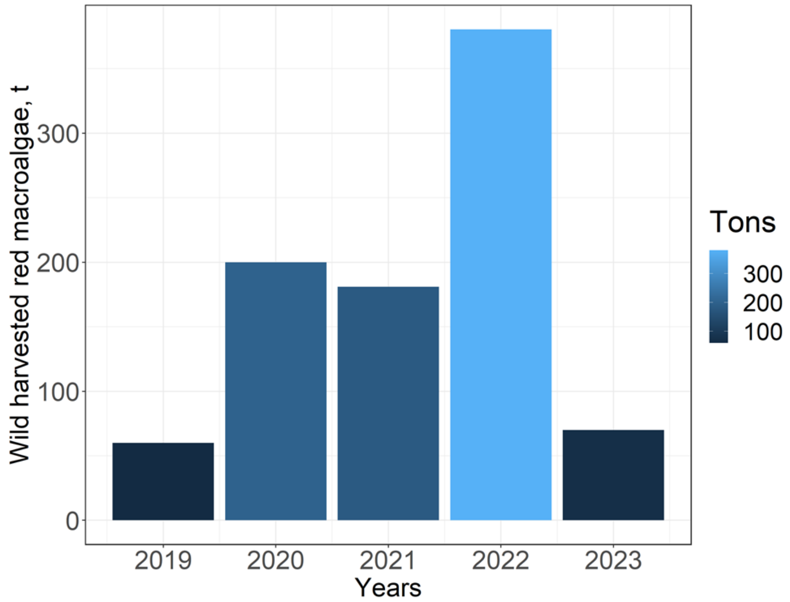

Figure 6. Amount in tonnes of wild harvested red macroalgae (*Furcellaria lumbricalis* and *Coccotylus truncatus*) in Estonian waters, source: https://pta.agri.ee/ettevotjale-tootjale-ja-turustajale/kutseline-kalapuuk/puugistatistika

Although beach-cast macroalgae gives the islanders an additional income opportunity, it is important to consider that weather conditions are always unpredictable, making beach cast an unreliable and unstable source.

Monitoring of the industrial red algae stock in Estonia

A monitoring programme is in place to track the recovery of the seaweed population. Every other year (previously each year), a new quota is calculated by the Estonian Marine Institute by measuring *F. lumbricalis* quantity and evaluating the biodiversity. Evaluation of harvesting places is being set as well – considering the proportion of seaweed mass, coverage, and all other species – plants and animals – that could be affected. A sustainable approach and not harming the natural reproduction rate are always kept in mind, within protecting all species in the area.

The following objectives are considered for monitoring the wild harvesting of unattached red macroalgae to achieve sustainable goals in the future:

1. The current status of the unattached red algae assemblage is assessed by examining the biological parameters that characterize the assemblage and their spatial variability, along with the physical parameters that define its growing environment.
2. Investigating whether trawling algae from the seabed has triggered opportunistic algal blooms, which may lead to oxygen depletion in the lower layers of the algae.
3. Provide harvesting recommendations for the two years following the study.
4. Assess the suitability of the area defined in Article 25(1)(5) of the Fisheries Code (CFC) for fishing in the two years following the survey.
5. The distribution patterns, i.e. the coverage, of the red algae population in Kassari Bay are determined based on a video method. This approach will enable a more accurate assessment of the distribution range and coverage of the loose red algae population, ultimately leading to more precise stock assessments in the future.

Quantitative samples are collected at 54 monitoring stations in the red algae distribution area during field surveys in Kassari Bay in July. A standard sized (20 x 20 cm) sampling frame is used to collect quantitative biomass samples by the diver. At each sampling point, the following parameters characterizing the red algae assemblage and its habitat are described and recorded by the diver:

- algal layer thickness (cm).
- total cover of the red algae community (%)
- type of sediment
- presence of stones/rocks

The following physical parameters are measured at all sampling points in parallel with the quantitative sampling:

- seawater temperature in the near-bottom layer (°C)
- seawater transparency in metres (Secchi disk)
- oxygen concentration in the near-bottom layer (mg l^{-1})

At the sampling point, plants and animals remaining in the sampling frame placed on the bottom by the diver are collected, packed in a plastic bag, labelled and stored in a cool (thermo-box) and dark place until laboratory analysis. All collected quantitative samples are analyzed immediately after collection without prior freezing to ensure the most accurate determination of wet weight.

During laboratory analysis of the algal material, the primary species of the red algal assemblage, *Furcellaria lumbricalis* and *Coccotylus truncatus*, are separated from the other animals and plants present in the sample. The wet weights of the main species in the red algal assemblage present in the frame sample (*F. lumbricalis* and *C. truncatus* separately) are determined, along with the wet weights of other macroalgal and zoobenthic species. Based on the results obtained, the biomass (g m^{-2}) of the red algal assemblage, the proportion (%) of *F. lumbricalis* and *C. truncatus* and other macroalgae and zoobenthos species are calculated separately for each sampling point, considering the overall coverage values. Since 2006, in addition to the wet weight of *F. lumbricalis*, the wet weight of its co-dominant *C. truncatus* has been determined separately in each sample, and the proportion calculated - given the potential future use of the latter for industrial purposes.

The distribution area of the red algae stock is defined as the region within Kassari Bay where the algal species that form the unattached red algae assemblage have a seabed cover of at least 10%, and the main species, *Furcellaria lumbricalis*, comprises more than 5% of the total assemblage biomass. This criterion has been considered when calculating the average biomass and biomass fraction, the average thickness of the algal layer and the overall coverage of the whole community and its different components. The distribution maps have been compiled considering the parameters recorded at all stations (54) in the study area. In the maps, the distribution boundary is defined as the 5 m depth contour (except the part of the study area on the Soela Strait side) (Palme & Herkül, 2023).

5.2.2. The case of Germany/Denmark

The harvesting of the raw material of bladderwrack by oceanBASIS

In Germany, *Fucus vesiculosus* (Fig.7) habitats have been reduced or have almost completely vanished due to the increasing eutrophication and turbidity of the water. It is therefore more than justified that the habitat has ended up on the Red List of endangered biotopes in Germany. Nowadays, the *Fucus* biotope is slowly recovering, but over-fertilization with nitrogen still exerts great environmental stress on macroalgae stocks. Therefore, despite the visible recovery of stocks in Germany, wild harvesting is not allowed (Meichssner et al., 2021). Unlike in Germany, the coastline in Denmark can be used by people after consultation with the authorities, including the harvesting of bladderwrack under controlled conditions. This enables the coastal population to appreciate and care for marine resources and to develop an awareness of their sustainable use. In Denmark, the concept of “ocean gardening” is therefore very successful. Anyone can sustainably cultivate and harvest algae, mussels or other marine organisms for their own use.

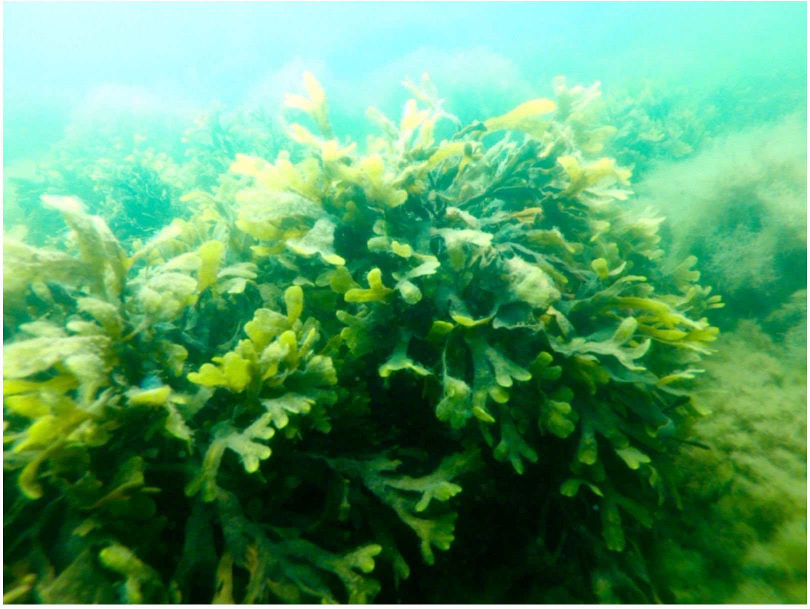

Figure 7. Bladderwrack *Fucus vesiculosus* in the coastal area of the Baltic Sea. Photo: Ieva Bārda

The German company oceanBASIS is currently relying on wild harvesting of Baltic Sea indigenous coastal marine algae for its biomass supply. In the case of oceanBASIS, the sister company CRM - Coastal Research & Management with 30 years' experience in topics of marine ecology research, is involved in the Schleswig-Holstein *Fucus* monitoring project on behalf of the State Office for the Environment and doing environmental research of wild *Fucus* harvesting in the Denmark on behalf of oceanBASIS. The harvesting area is mainly located in Begtrup Bay east of Aarhus, adjacent to Mols Bjerge National Park. The responsible municipality has leased an area to the Danish cooperation partner of oceanBASIS and permitted the use of algae on the condition that annual monitoring and documentation of the algae stocks and environmental conditions is carried out. A mandatory procedure titled "Self-monitoring for ecological algae harvesting in the Begtrup Vig-Dragsmur coastal system" is also performed at the time of harvesting. The document of monitoring results must contain all relevant information about the harvest, including environmental data and the harvesting material and personnel involved. Prerequisites for obtaining the licence include that no more than 10% of the algae stocks may be harvested per year in 1-2 alternating areas out of a total of 5 areas. This means that, on average, the same areas have a fallow period of three years.

The harvesting processes

Once a year, 3-4 oceanBASIS employees travel to Begtrup Bay for 1-2 days and harvest *Fucus vesiculosus* in waders and by hand at a water depth of up to 80 cm. Harvesting takes place in autumn when the water temperature is higher than in the spring. By this time, most aquatic organisms have completed their annual growth cycle and/or reproduction. The plant parts that have grown in spring and summer are also not yet so heavily covered with barnacles or other epiphytic organisms.

The harvest is carried out completely manually and the algae are selected individually. The harvesting method consists of partially cutting off the upper half of individual *Fucus* tufts. In the case of very dense stands, whole algae are also harvested up to a maximum of 10% of the overgrown area. The harvested algae or pieces of algae are rinsed in Baltic Sea water and placed in the harvesting basket. The trained harvesters move carefully along uncovered areas. This reduces the risk of damage to the algae or the surrounding ecosystem. The harvesting baskets are brought ashore, and the algae are placed on a sieve for inspection and draining (Piker, 2024).

6. RECOMMENDATIONS FOR MONITORING OF SUSTAINABLE WILD HARVESTING

The first step, as the best sustainable practices advise, should be estimations of algae standing stock prior to any commercial harvesting, in addition to assessments of density or percentage cover, reproductive and growth season of target species (Bailey & Owen 2014). To achieve sustainability for selected species, a robust and extensive survey of standing stock and aerial extent of targeted species should be conducted to establish a reliable baseline against which to monitor change. Following the initial survey, population-level data should be used to determine what level of sampling would be required to detect different thresholds of change (i.e. 10, 20, 50% loss). A variety of survey methods are available for monitoring, including shore-based surveys (along transects, grids or haphazardly as appropriate) on species' abundance, biomass and distribution, and remotely sensed imagery (i.e. from satellites, aerial surveys or drones) appropriate for larger species. Species distribution models can be used to estimate the likely abundance and biomass of targeted species, and to extrapolate from survey sites to the wider region, indicating areas likely to be vulnerable to harvesting impacts or other local pressures (Wilding et al., 2021a). It should be noted though that lack of harmonized data on algae standing stock is one of obstacles towards seaweed industry development in Europe (Vazquez Calderon & Sanchez Lopez,2022).

6.1. Environmental parameters

All monitoring activities of sustainable wild harvesting and beach cast collecting should be either species-specific or site-specific or at least country-specific, considering harvested method used, and no all-fitting scrupulous recommendations can be provided. According to EMODnet data portal, currently the macroalgae production is in the Atlantic region of the Europe with very few exceptions in other marine areas (Fig.8).

Manual harvesting locations (companies) in Europe

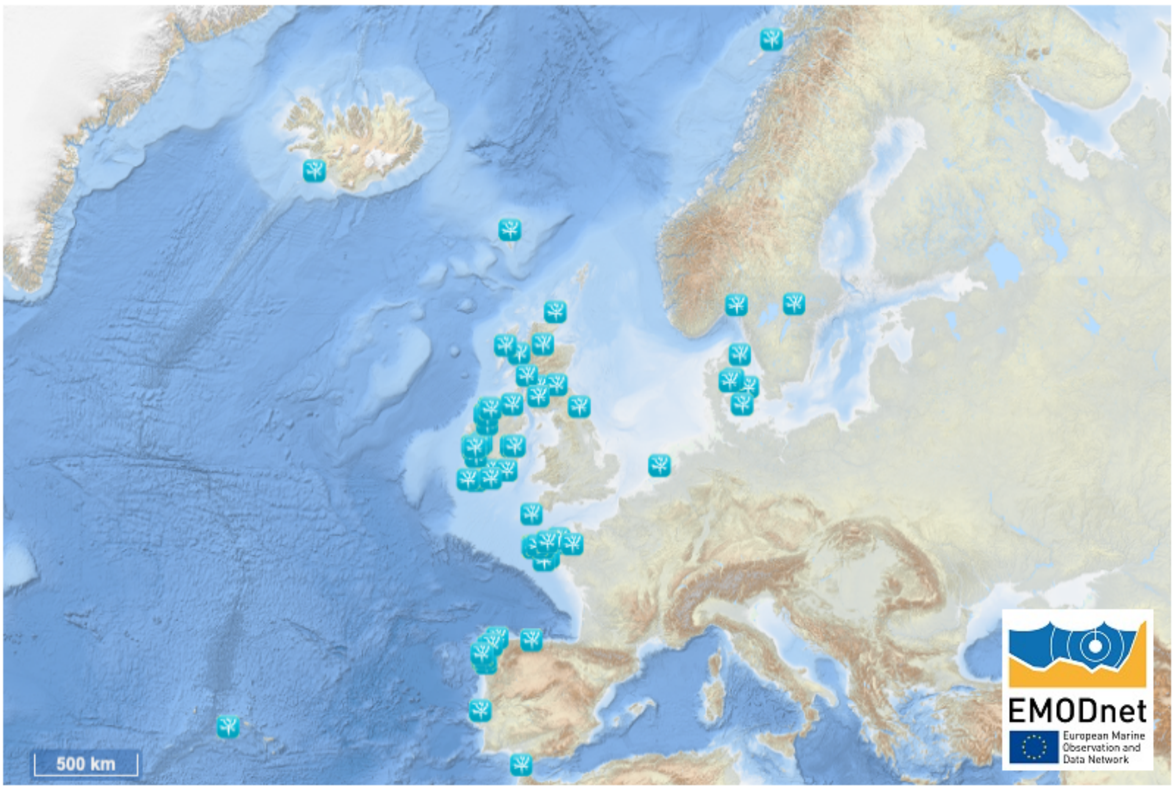

Figure 8. Locations (companies) of manual and mechanical seaweed harvesting in Europe, EMODnet data theme "Human activities/Algae production"

The dominance of the Atlantic region in macroalgae wild harvesting is related to the geographical distribution, the larger extension of the intertidal area and a higher abundance and dimension of seaweed species traditionally exploited at an industrial scale there (Araújo et al., 2021). In comparison with the Atlantic region, macroalgae species diversity in most parts of the Baltic Sea is up to two times lower, with the algae being smaller in size and biomass. This difference is primarily due to a combination of lower salinity and increased water turbidity caused by eutrophication. Additionally, the proportion of short-lived opportunistic species has grown, leading to a greater accumulation of beach wrack (Weinberger et al., 2019).

Still, to make the first step – i.e. to estimate baseline for monitoring on sites in combination with species distribution models for wider regions – some common parameters are suggested together with sampling/observation frequency. The recommendations are summarized in Table 3 below.

Parameter	Units or features	Frequency
Coverage of area by species or algae layer thickness	% or cm	Annually
Type of substrate/sediment	Pebbles, rocks, sand - composition as %	Annually
Biomass of target species at selected sites	Sample collected, wet weight estimated g m-2	Annually

Species composition in the area	Video observation and/or sample collected, wet weight estimated g m^{-2}	Annually
Water temperature	°C	Annually
Water transparency	Secchi disc measurement, m	Annually
Dissolved oxygen concentration	mg l^{-1}	Annually

For monitoring beach cast collection, it is recommended to track the concentration of potentially hazardous substances, such as cadmium, especially if the beach cast is intended for use as agricultural fertilizer. The need for this recommendation is site-specific, as cadmium pollution levels vary by location. Additionally, given the trends of warmer air and water temperatures, it would be beneficial to conduct surveys for pathogenic microorganisms in beach cast accumulation areas during the active recreational season.

6.2. Legal aspects

Like aquaculture regulations, wild harvesting of seaweeds and beach cast collection is a responsibility of EU Member States. Therefore, based on reviewed information, it is possible to provide some general comments regarding policy planning and legislation:

1) Include the areas of wild harvesting and beach cast collection in spatial plans - either MSPs or regional territorial planning;
2) Monitoring of areas of wild harvesting and compound concentration surveys of beach cast would be more sustainable if included in the national monitoring programmes;
3) Governance sharing between national authorities and communities could strengthen the local responsibility regarding wild seaweed resources and help securing sustainability;
4) Inclusion of other forms of cooperation in monitoring seaweed harvesting - transnational or trans-sectoral or citizen science - could be considered.

6.3. Economic requirements

Economic feasibility is often a complex issue for environmental monitoring, including costs and benefits, cost sharing, market demand, data sharing and continuous funding. In European countries where wild harvesting of seaweeds is a part of industry, the monitoring is either funded by the industrial actors themselves (in Denmark), by the government (in Estonia) or costs are shared (Ireland). In some cases, no monitoring is present, but the sustainability of a harvest is secured by self-determined fallow periods of certain areas by company (Windig et al., 2021a).

Cost-sharing could be one suggestion for the economic sustainability of monitoring, especially in those cases with interest from the industry. Joint research projects with harvesting relevant data collection could be also supported.

The development and application of remote observation methods together with modelling tools could gradually decrease the costs of manpower needed for field observations and measurements. At the initial stage, investments in technologies and infrastructure will be needed, though.

At the same time, we cannot ignore the present situation where wild harvesting in Europe is expected to become less important due to climate change, growing human population impacts and decreasing biodiversity. Seaweed cultivation in the form of regenerative ocean farming, algal marine or land-based farms is planned as the source of biomass for various industrial purposes. We can expect wild harvesting gradually changing from industrial to artisanal range, and wild seaweed mostly used for personal use.

CONCLUSIONS

Wild harvesting is still the most important method of macroalgae biomass production in Europe, and manual harvesting is the most frequent method of collection. Exploitation of natural macroalgal stocks – both harvesting and beach cast collection – should be performed sustainably for several relevant reasons. Seaweeds provide ecosystem services, secure habitat biodiversity, reduce coastal erosion, absorb carbon dioxide and contribute to carbon sequestration, as well as assimilate excess nutrients in eutrophied areas. Therefore, unsustainable overharvesting can disrupt balance in the entire marine ecosystem, increase seabed erosion and damage to shorelines, diminish macroalgal capacity to mitigate climate change and reduce long-term yields of seaweed for future use.

To ensure sustainability of seaweed wild harvesting, several factors must be respected:

- geographical distribution of species, as living at the range edge brings additional environmental stresses that may reduce growth rate and post-harvest recovery. The production from the harvest may also be affected also by climate change with warming seas, shifting the range borders.
- various life histories of macroalgae species, affecting the time of maturity and rate of recovery.
- recovery potential of each species, observing periods of peak growth, considering reproduction and recruitment differences.
- the scale of the created ecological impacts due to seaweed removal, as the level of impact correlates with intensity and frequency of harvesting. Extensive removal of native species can enhance development of non-native or opportunistic species with reduced value for habitats.
- collection or removal of beach cast in most cases should also follow the principles of sustainability, as beach cast serves as part of coastal food webs. Still, in eutrophied or polluted areas complete removal could be advised due to leakage of nutrients and pollutants from decaying algae.

Sustainability aspects of seaweed harvesting are included in national regulations of the countries where seaweed is regarded as a valuable resource, mostly on the Atlantic coast (France, UK, Norway). In the Baltic Sea area, Estonia is the only country where industrial scale wild harvesting is allowed. Harvesting management systems are founded on a licensing process and involve collaboration between national authorities and fisher organizations, or close cooperation between authorities, research institutions, and the industry. The regulated aspects of harvesting include:

- size and location of area;
- species, collection specifics (e.g. allowed cutting length) and quota;
- period of harvesting;
- control of harvested area.

Accurately estimating the seaweed standing stock is crucial for initiating monitoring of wild harvesting and evaluating its sustainability. A combination of methods – direct surveys, remote observations and modelling – could provide a reliable baseline as a starting point for monitoring the changes. Priority monitoring parameters applicable in most of the cases include characteristics of algae and basic environmental indices. Examples provided from Estonia and Denmark demonstrate good knowledge of baseline and balanced management decisions.

Monitoring of beach cast quality regarding cadmium concentrations is relevant, if the beach cast is intended for use as agricultural fertilizer. Surveys for pathogenic microorganisms are recommended in beach cast accumulation areas during the active recreational season.

EU level regulatory documents addressing macroalgae are limited, mostly focusing on seaweed cultivation. Like aquaculture, wild harvesting of seaweeds and beach cast collection is a responsibility of EU Member States. Recommendations for national policy support include suggestions to establish a link between wild harvesting sites and national MSPs, share a governance of local seaweed resources and try new forms of cooperation for monitoring of harvesting. Joint projects and cost sharing could also be recommended for reducing the costs of monitoring.

The EU Algae Initiative has invited Member States to fill the knowledge gaps on the impacts of seaweed wild harvesting and on estimates of beach cast amounts. However, in the Baltic Sea region, development of macroalgal cultivation is regarded as more feasible and promising than wild harvesting due to vulnerable and strictly protected habitats of wild seaweed. In the light of projected climate change, the importance of wild harvesting could decrease also in other parts of the EU. Then collection of seaweed for artisanal and personal use would replace industrial range of harvesting.

A very recent modelling study of European seaweed aquaculture perspectives describes the Atlantic region as the best for large-scale cultivation, specifically for cold-water (brown macroalgae) and intermediate-water species (green and red macroalgae). The potential cultivation area is estimated at over 1 million km^2, and occupying only 1% of that area could yield a yearly production of over 30 million tonnes dry weight. Adding realistic logistical constraints (water depth and distance to coast) further limit the potential production to 5 million tonnes per year, only in EU member states' waters (Macias et al., 2025). The authors emphasize that cultivation at this scale could also result in unintended ecosystem impacts, such as alterations to biogeochemical cycles. As these impacts have the potential to be locally significant, further investigations focusing on long-term sustainability aspects of this activity are of utmost importance.

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