GENetic diversity exploitation for Innovative macro-AlGal biorefinery

Deliverable 6.9

Manual on the best practices for seaweed farming, including biocontainment and management of pests and pathogens

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Summary

The knowledge created in WP6 was used, as foreseen in the DoA, to develop best practices in order to improve management of seaweed cultivation, mostly to decrease potential environmental impacts, and increase biosecurity, and social acceptability of this activity.

This is a practically-oriented, manual of best practices for seaweed farming. It is based on GENIALG work and expertise, and is not exhaustive. It deals especially with (a) long-line cultivation of laminarian seaweeds, especially *Saccharina latissima*, and (b) on-land cultivation of sea-lettuce, *Ulva* spp. However, most recommendations apply to similar species farmed in the same way.

It includes sections on:

- Finding a species and site
- Contributions to the business plan
- Biosecurity
- Environment and Monitoring
- Social Licence
- Harvesting, storage and food safety
- Further reading, to find more detail about these matters.

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1 Introduction

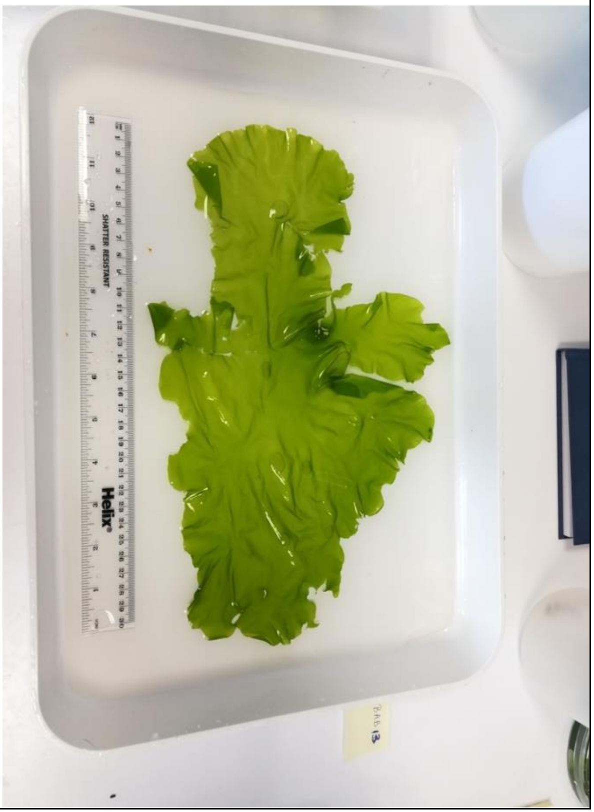
Cultivation of seaweeds is increasing in amount and importance. This guide is intended for persons or companies operating a seaweed farm, or planning to do so. It may also be useful for regulators of such farming and for those in charge of marine planning. It provides, briefly, some recommendations for good practice based on research carried out by the H2020 GENIALG project, and drawing on the expertise of members of the project. In order to make concrete statements, we consider (a) long-line cultivation of laminarian seaweeds, especially *Saccharina latissima*, and (b) on-land cultivation of sea-lettuce, *Ulva* spp. However, most recommendations apply to similar species farmed in the same way.

As far as possible the recommendations are based on scientific knowledge, and the section 'Further Reading' provides links to more detailed accounts of this knowledge. Where knowledge is lacking, we have invoked the 'precautionary principle' in order to minimise risk to business and environment. We have arranged the topics in an order that corresponds to the way they might arise during the planning or operation of a farm.

Recommendations are not exhaustive, and other documents should be consulted.

A number of biological terms are used. *Those in **green italics*** are explained in the Glossary.

The two seaweeds considered in this document.

Sugar kelp (*Saccharina latissima*) being harvested from a long line in Scotland	Sea lettuce (*Ulva* sp.) from a Scottish beach
	

(Photographs: Marie-Matthilde Perrineau, SAMS)

2 Finding a species and site

A number of issues should be considered in deciding what to farm and where to farm it. All of these will influence the farm's costs and earnings, although we don't explicitly consider finances in this document.

- biological (key species characteristics);
- environmental (conditions needed for growth of selected species);
- technical (what sort of gear is needed and under what sorts of conditions can it be deployed?);
- legal (regulations and planning policies);
- social (will local communities support or oppose a farm?);
- other sea-users and sea-uses.
- Water quality suitable for target markets

2.1 Biological, environmental and technical factors

In this document we use sugar kelp and sea-lettuce as examples, and Table *1* compares the key biological characteristics, environmental dependencies, and cultivation requirements, of these two examples.

Table 1 Key biological characteristics, environmental dependencies, and cultivation requirements of *Saccharina latissima* and *Ulva* spp.

	Sugar kelp, *Saccharina latissima*	Sea-lettuce, *Ulva* spp.
Key biological characteristics	Sugar kelp are brown seaweeds (class *Phaeophyceae)* with an *alternation of generations*: The adults are *sporophytes* (*diploid*) which grow up to metres in length). These release spores which develop into microscopic *haploid gametophytes* (male/female) as an independent lifestage. The gametophytes grow as filaments (strings of cells). If conditions are suitable, fertilisation occurs and a new adult sporophyte begins to grow.	*Ulva* spp. are green alga (phylum *Chlorophyta*) with an *alternation of generations*: *haploid gametophytes* are morphologically similar to the *diploid sporophytes*. Compared with other commercially cultivated seaweeds, *Ulva* is a fast-growing species. However, large variation in productivity is observed, both within species and between *Ulva* species. Compared to kelp species, it can be grown through vegetative propagation, and under the right conditions, year-round and with multiple harvests. *Ulva* blades are small (average 15-30cm) and a weight of 15-30g wet.

	Sugar kelp, *Saccharina latissima*	Sea-lettuce, *Ulva* spp.
Main environmental requirements for cultivation	Sugar kelp are adapted to survival in cold, turbulent and transparent seawater containing naturally high concentrations of *nitrates* and *phosphates* during winter. They are distributed in the Northern cold temperature region of the Atlantic and Pacific.	*Ulva* grows better in calm, inorganic nutrient rich, and warm waters. In the Netherlands, *Ulva* species generally show maximum productivity during the summer period. Little or no growth is observed from late autumn to spring. In Southern Europe, it has positive growth year-round, peaking in seasons with long photoperiods.
Temperature	Sugar kelp grow well in cold seawater (optimal range 5-15°C). They are not found in many areas of southern Europe as growth is poor at 17-21°C. Death occurs at higher temperatures.	*Ulva* grows best with average temperatures between 18º-20ºC, although they present a wide tolerable range, from 12 to 28 °C. In the Netherlands, during hot summers like those in 2019 and 2020, little growth was observed (day-time temperature up to 40 ºC), and signs of sporulation were observed.
Salinity	Sugar kelp grows best in near full salinity seawater (24-35 psu). Reduced or fluctuating salinity, such as in many fjordic systems, can reduce growth (15-21 psu) or even death. Freshwater pulses due to rainfall/runoff may lead to substantially reductions in surface seawater salinity which may cause death of sugar kelp within a few days.	The genus *Ulva* has a world-wide distribution including freshwater as well as marine environments. Species differ in their tolerances of low salinity. However, for consistent production, water should be in near full salinity water (30-36 psu).

	Sugar kelp, *Saccharina latissima*	Sea-lettuce, *Ulva* spp.
Typical cultivation method	Open seawater cultivation. *Sporophytes* are grown on ropes that are suspended near the surface of the water. Generally, 1-3 m depth is considered optimal, depending on water clarity: Too near the surface and the high light will reduce growth, too deep and there is insufficient light for growth. Cultivation ropes are often stretched in long runs (50-100 m) horizontally below the surface. Vertical droppers/looping longlines are also used, similar to in mussel cultivation. The choice will depend on the infrastructure available and scale of cultivation.	Land based cultivation, in mono-culture or in integrated multi-trophic systems. Can be grown in circular, rectangular tanks or in raceway systems. Daily input flux of nutrients should be such that it exceeds the daily demand of the cultivated biomass. Protocols for optimizing stocking density, nutrient flow and harvest frequency are species, location and season dependent.
Propagation method/Obtaining seed	Hatcheries or nurseries maintain populations of gametophytes, from which cultivation ropes can be seeded with young sporophytes (<1 cm)	*Ulva* commercial production is mostly done by vegetative propagation. However, trials for seeding long-line systems with spores has been attempted.
Typical growth period	Seeded cultivation ropes are deployed in the Autumn. The crop of adult sporophytes is harvested in the following late spring-early summer (April-June). The timing of deployment and harvest will likely need to be optimised for the cultivation site and product. Deployment will be influenced by sea surface temperature and light availability. Biofouling (overgrowth) by other organisms and a slowing of growth during the summer are key considerations for the timing of harvest. Both of these are influenced by the local environmental conditions (temperature, salinity, nutrients), which can vary between years.	In the Netherlands, *Ulva* species generally show maximum productivity during the summer period. Little or no growth is observed from late autumn to spring. In Portugal, *Ulva rigida* can be grown year-round, with multiple harvests – average yields of 3kg fresh weight/m^2/month. Positive growth occurs year-round, despite higher yields registered in spring-summer periods (5-7kg/m^2/month).

	Sugar kelp, *Saccharina latissima*	Sea-lettuce, *Ulva* spp.
Yields	Variable between sites and years. Northern sites in GENIALG (France, Ireland, Norway) obtained between 7.8 and 20.5 kg wet weight per metre of long-line, whereas southern sites (Portugal) obtained 0.2 to 0.6 kg/m. Overall, protein content varied from 5.3 to 15.5 % of dry weight. Carbohydrates were 39 to 53% of dry weight.	*Ulva* production at a GENIALG IMTA site in Portugal totalled 442 tonnes wet weight per hectare per year, with regular harvesting. Protein content averaged 17.5 (sd 4.9)% of dry weight. Current protocol allows a consistent content of 20-23% dry weight. Best yields were obtained at low stocking density; at higher stocking density, the yield is sensitive to water flow and nitrogen supply rate (from farmed fish)
Typical products or use	Sugar kelp tends to be grown for use as a human food additive e.g. as dried flakes or as an ingredient in prepared products e.g. pesto. It has potential as a large-scale crop for animal feed or component extracts, similar to many other seaweeds.	*Ulva* (sea lettuce) is mostly sold for human food, in dry (flakes) or fresh formats, as a sea vegetable or as a food ingredient (integrating sauces, dairy, pasta, pestos). The size of this market in Europe reaches easily over 2000tons fresh weight. Other potential markets, for now still on the sphere of R&D, are feed additive (*Ulva* powder), ulvan extracts for nutraceutics or biomaterials, and raw-material for bioplastics (frozen).

Seawater temperatures are often recorded, and so the temperature fluctuations of a proposed cultivation site can be estimated. However, local conditions may vary in specific geographical regions/ at nearshore sites e.g. enclosed shallow areas. Consider monitoring before cultivation begins.

Salinity fluctuations in coastal areas can be highly localised depending on the geography of the area. Due to the risk of crop death, it is recommended to carefully research any salinity fluctuations near the cultivation site and known source of freshwater/brackish water discharge e.g. estuaries. Long-term monitoring may be available from local aquaculture installations.

2.2 Potential for strain selection in seaweed aquaculture

Currently in Europe the aquaculture of macroalgae is largely based on wild local populations of the species of interests. The main reason is the recent development of this industry which has not yet had time to "domesticate" these species as the traditional agriculture did. However, this approach has advantages such as i) avoiding the introduction of non-native species/cultivars in open environment, as well as co-cultivated potential pathogens, ii) maintaining a sufficiently high level of crop genetic diversity necessary for resistance against potential abiotic and biotic stresses. In the cases of sugar kelp and sea lettuce, the selection of local individuals used to generate the seed stock is based on their geographical location, ideally close to the seaweed farm (or nursery) and their accessibility and fertility during the sampling campaign. However, the result is that yield and other traits of agronomic interest will differ from year to year, independently from external factors such as the environment. This situation can be improved by selective breeding.

2.2.1 The case of Saccharina latissima

Saccharina latissima shows substantial genetic differentiation across Europe which is explained not only by geographic distances but also by local currents, habitat discontinuity and historical demographic events. Thus, certain sugar kelp populations distant from each other by ten or hundred kilometres might present distinct genetic diversity.

During the Genialg project, a biobank was established to make available strains representing much of the genetic diversity of *Saccharina latissima* in Europe. Populations were sampled at 23 locations in 7 countries. For each population, a maximum of 24 gametophytes have been isolated, with a sex ratio of 1:1. A total of 426 clonal gametophytes have been cryopreserved and are available from the Culture Collection of Algae and Protozoa (https://www.ccap.ac.uk). Genomic data will soon be available for these strains. For those with the facilities to cultivate the gametophytes, use of location-appropriate strains, and experiments to find the best varieties for local conditions, is encouraged.

2.2.2 The case of Ulva spp.

In Europe, randomly chosen local samples are usually used as initial cultures for offshore and on-shore farming. Hence, yield(s) can significantly vary year on year due to the use of different seeded material from different genetic makeup. Some recent studies have shown that protein content can vary from 5 to 25% of the biomass, and growth rate from 9 to 30% per day, depending on the *strain* and *species* of *Ulva* used. Thus, we encourage seaweed growers to perform similar experiments on their local strains, in order to select the best performing ones prior to large scale cultivation.

The selection of strains could be made on several traits, as selecting fast growing strains does not appear to be at the expense of protein content, for example. As well selecting for high protein content can be achieved while maintaining a high carbohydrate content. Hence seaweed cultivators could grow highly nutritious elite *Ulva* seaweeds, containing similar levels of proteins compared to soybean and *Ulva* biomass could be envisaged as an alternative to land-based plant protein sources.

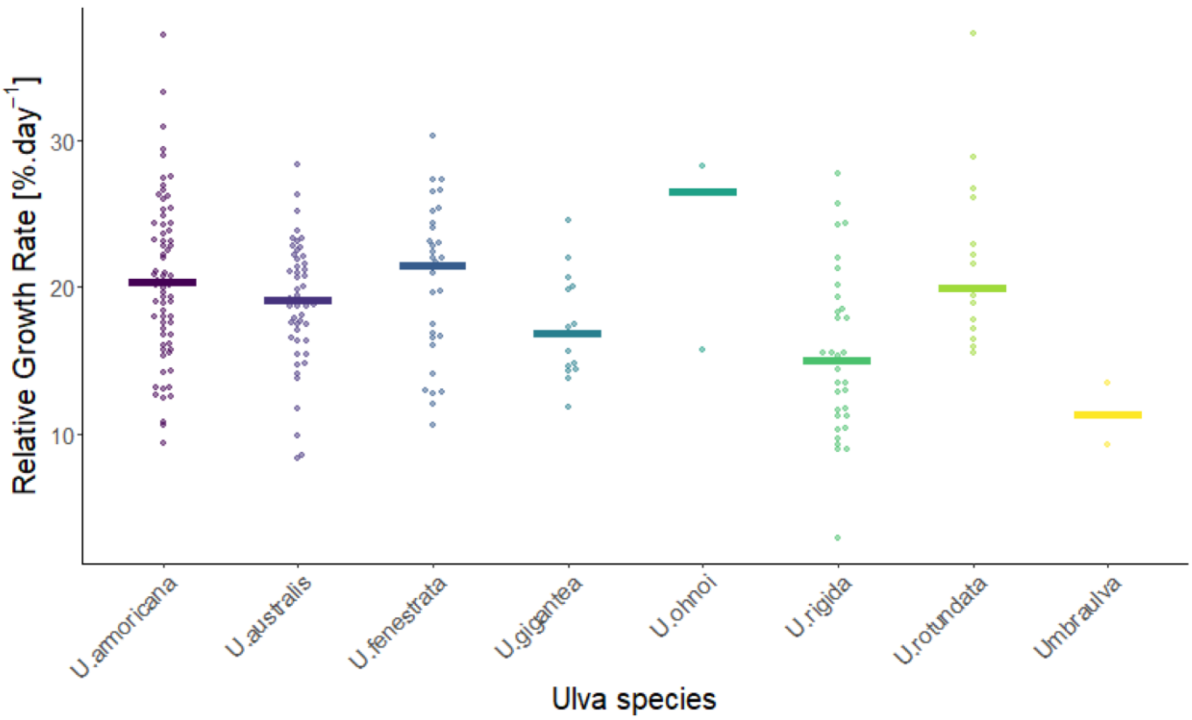


Figure 1 Relative growth rate of Ulva species.

Each dot represents an individual sample; lines represent median values for the species.

In addition to the variability in phenotypes we observed for individual *Ulva* samples, we also observed variations between species for growth and some nutritional traits. For instance, individuals belonging to *Ulva rigida* are, on average, growing slower than individuals belonging to *U. rotundata, U. armoricana* or *U. fenestrata* (Figure 1). Such species effects could dictate which species could/should be selected for specific uses in aquaculture, and pre-screening of the potential of different species could highlight the best target species for a particular aquaculture system. The strategy to mono-strain farms needs to be validated on real, commercial scale farming conditions, as through time, mono-strains can be affected more easily by disease and crash-causing stress.

2.3 Regulatory, marine planning and social factors

Following identification of suitable environmental conditions for seaweed farming, and consideration of technical and business factors, it will also be necessary to consider some additional requirements imposed by society. These fall under two headings:

- the need for legally-sound permissions or licences, granted by public authorities, to use an area of sea or of land near the sea, and to impact on the environment;

- the need to manage informal interactions with the maritime communities that have an interest in the use of the sea or in new developments on-shore.

2.3.1 Legal permissions

The situation is complicated and in many countries not yet well defined. Occupation of space at sea may be regulated by Marine Planning laws introduced under the EU Maritime Spatial Planning Directive or similar, together with requirements to avoid interference with navigation and to assess potential environmental impact. Development of shore-based farms, and support facilities for offshore farms, are controlled by Town & Country Planning laws specific to countries and regions within country. As GENIALG has not studied these aspects, we merely exemplify some of the issues for two countries in Table 2.

Table 2 Some legal regulations relating to seaweed aquaculture.

	Kelp cultivation in Scotland using long-lines in coastal waters	Sea lettuce farming as part of shore-based (transition waters) IMTA in Portugal
EIA and environmental licence requirement	No EIA formally required unless farm is likely to impact Marine Protected Area, and no environmental licence necessary; however, environmental considerations will be taken into account during site licence application	New farm (mono-culture or IMTA) – will require a EIA that is part of a new aquaculture licence (involves validation by Environmental Agency (APA/ARH) and Nature Conservation Institute (ICNF). Every year, water analysis is mandatory (input and effluent) and should be sent to Environmental Agency (APA/ARH). Operating farm, organic certified – water should be classified in A or B according to Water framework directive. Above 20tons/year (fresh weight) production, a simple EIA is required by the certification entities.
Planning	Not well defined at present; no seaweed farming zones designated in Scotland's Marine Plan; there is a presumption against farms exceeding 10 hectares; anything larger than 1 hectare requires a public consultation.	Aquaculture areas (at-sea or in transition waters) are defined by a National Plan. Currently there is no differentiation according to trophic level (under discussion).

	Kelp cultivation in Scotland using long-lines in coastal waters	Sea lettuce farming as part of shore-based (transition waters) IMTA in Portugal
Site license	Site license ('Algal Farms Marine Licence') must be obtained from Marine Scotland, a department of the Scottish Government (which has powers devolved from the UK government); various stakeholders will be consulted	Licenses (Licença de exploração aquícola) are obtained from DGRM (Marine Resources Governmental Department). Several other institutional entities are consulted and should approve (APA, ICNF, IPMA, CCDR). Besides general EIA considerations, the species to be farmed should be listed and exotic species are to be excluded.
Leasing	Sea-bed lease must be obtained from Crown Estate Scotland, a quasi-public-body	In Portugal, the Maritime Public Domain includes all water basins and its margins (50m from the high-tide level). For operations in those areas, a lease ("concessão") must be obtained from the state. Exceptions are made in on-shore/transition areas where exploitation activities were carried out (ancient salt-ponds for instance) and that were proven to be Private (long process). Even if Private if a transaction of property is to be made, the State has priority rights.
Other	Commercial farms advised to locate in a Shellfish Waters Protected Area in order to obtain a business licence	IMTA licences for one farm, cannot be held by 2 companies (the ideal scenario, one with the fish, the other with the seaweed).

2.3.2 Social factors

Those engaging in seaweed cultivation need to understand and manage their interactions with local *stakeholder*s and *communities* in order to minimise business risk, operational efficiency, and access to new sites. Maintaining good relationships will be addressed in section 6, under the heading of 'Social Licence to Operate'. The present subsection deals with interactions that may contribute positively or negatively to public planning and permitting processes. For example, a Social Impact Assessment may be required as a part of a wider Environmental Impact Assessment when applying for a concession. Evidence of stakeholder consultation with community representatives, members of the public and other users of the sea, and critically their lack of objections to the proposed activity, can also be a requirement for permissions. Therefore, we provide here a brief overview of what a **Social Impact**

Assessment can be and resources for further reading. We also outline good-practice principals for **stakeholder engagement** and relevant resources.

Social Impact Assessment (SIA) is the process of identifying the social interactions of an activity, typically used to classify and mitigate for negative impacts. There are very few instances of where companies/ organisations set out to deliberately cause harm to the communities the operate in, however there can often be unintended consequences. Equally, SIA can help to characterise opportunities for enhancing the benefits of the activity for the local community and wider society. SIA requirements vary from country to country and in some cases are embedded within Environmental Impact Assessment (EIA) or are not present at all. It is advisable to seek expert opinions on an SIA/ EIA requirement for your site and scale of activity.

The basic principles of SIA include: understanding the local and regional context of the activity; providing quality information for decisions to be based on; assessing the activity's interactions with human rights and associated laws and good practice; assessing and ensuring environmental justice aspects are addressed; inclusion of local ecological knowledge; appropriate use of methods and evaluation tools; action on findings through mitigation measures, effective community and stakeholder engagement and consultation, and compensation where appropriate. A comprehensive guide to SIA can be found in the International Association for Impact Assessment's guide on Social Impact Assessment: https://www.iaia.org/uploads/pdf/SIA_Guidance_Document_IAIA.pdf

Stakeholder engagement Stakeholder engagement is widely seen as essential to effective marine spatial planning processes. Some countries make it a requirement for licensing for specific activities. It can help to optimise use of space, reduce conflict in areas of co-location or multi-use, advance studies on environmental, social, and cumulative impacts, and reduce the likelihood of misinformation spread through informal channels.

Typically, two kinds of stakeholders must be consulted. The first kind (regulatory stakeholders) are organisations with specific responsibilities under law for matters such as environmental and heritage protection, health and safety, maintenance of navigation, etc. The second kind are other users of the area and its resources. These stakeholders can include fisheries, other aquaculture producers, marine tourism, shipping and transport, military operators, renewable energy, subsea infrastructure operators (Oil and gas, telecoms). It is important to also consider coastal land-based stakeholders such as local community organisations, tourism businesses and non-governmental environmental protection organisations. It is advantageous to assess whether the proposed location of a site is near coastal areas that have designated visual, ecological, conservation or cultural status as these can interact with the scope and scale of stakeholder engagement.

The basic level of stakeholder engagement involves consultation and information provision. This is often all that is required by regulatory organisations, but it is insufficient to build the trust and personal relationships that are prerequisites for resolving contentious issues, should they arise. Ideally, stakeholders should get some say in project design or become part owners of the project. Here are some suggestions for effective stakeholder engagement for a new seaweed concession:

- **Get to know administrative/ legal obligations:** consider the requirements for a concession as set out by the administrative and legal obligations in your area and ensure the framework for engagement meets, or preferably, exceeds these requirements.
- **Define the aim, goals, and timeline of the engagement:** ensure that each meeting with stakeholders has a specific and defined purpose, with activities that are designed to meet that purpose. This can help direct discussions, improve reporting, and increase transparency over the actions required after each meeting, and the timescales that stakeholders can expect information/ decisions to be published.
- **Understand the context of the area:** the culture and context of an area can influence the methods used and location of engagement, the number of stakeholders, and the appropriate peripheral-but-important factors such as catering. It can help to have a single, local point of contact for stakeholders.
- **Stakeholder identification:** ensure a *stakeholder mapping* process is undertaken as early as possible to increase involvement and reduce the likelihood of negative feelings because of omission of stakeholders.
- **Design and preparation:** stakeholders often have limited time, so it is important to ensure that each meeting is well designed, runs on time, and that *facilitators* are fully prepared. It is good practice to have a trial run with facilitators and developers to identify and resolve problems.
- **Professional participation designers and facilitators:** if the proposed activity or project is large, it will be cost-effective and more efficient to hire professional participation designers and facilitators. Typically, these professionals will work with the developer on the goals and aims of the engagement, so that they can use methods and facilitate activities that are appropriate.
- **Clarity over what stakeholders can expect from the process**: ensuring that stakeholders know what the aims of the engagement are, will help to manage their expectations and holds the developer accountable for any changes or reporting made as a result of the engagement processes.

- **Evaluating engagement:** the importance of evaluating engagement processes cannot be understated. Reflecting on how each event went, assessing it against the goals of the processes, and incorporating any feedback from stakeholders on the processes can improve any further engagement activities. It can also help build stakeholder-developer relationships and transparency through open reporting of these evaluations. Any outputs should include both the positive and negative aspects of the engagement activities.

Table 3 Resources for Social Impact Assessment and Stakeholder engagement.

Social Impact Assessment	Resource
Human rights – the United Nations Guiding Principles on Business and Human Rights	www.ohchr.org/documents/publications/
Human rights, employment and industrial relations, stakeholder engagement – OECD Declaration on International Investment and Multinational Enterprises	legalinstruments.oecd.org/
Indigenous and Tribal Peoples – The International and Tribal Peoples Convention, Article 7(3)	www.ilo.org/
Stakeholder engagement	**Resource**
A good practice handbook for companies doing business in emerging markets – World Bank Group	www.ifc.org/
Stakeholder engagement – European Marine Spatial Planning Platform	www.msp-platform.eu/faq/stakeholder-involvement
A Typology of Stakeholders and Guidelines for Engagement in Transdisciplinary, Participatory Processes – Newton and Elliott 2016	DOI: 10.3389/fmars.2016.00230

3 Contributions to the business plan

Three of the topics studied by GENIALG, in its environmental and social impact section, are relevant to the development of a business plan for seaweed farming:

1. Environmental carrying capacity for seaweed – what is the maximum productivity (per hectare) of the chosen species and site? what is the maximum density of seaweed that can be farmed without adverse environmental impact?
2. Social carrying capacity – what size of farm might be acceptable to local communities or can be accommodated by maritime spatial planning along with other uses?
3. Ecosystem services provided by the seaweed farming, which can in some cases be monetised to increase farm income, or in other cases help to increase social carrying capacity.

3.1 Environmental Carrying Capacity

By the environmental carrying capacity (ECC) of a site or a region for seaweed farming is meant the amount (biomass) of seaweed of a chosen species that may be cultivated without considerably changing the conditions for the growth of the species or other parts of the marine ecosystem. The limit set to the growth of the species is called the **production carrying capacity**, and the limit set to avoid undesirable impact on other parts of the ecosystem is called the **ecological carrying capacity**.

The variables that are of the greatest importance in this context are those whose values are directly affected by seaweed aquaculture: mineral nutrient and oxygen concentrations, CO_2 levels, light penetration and organic loading. These are variables already managed through the European Water Framework Directive, and in many cases there are regulations in place that limit changes and hence control the ecological carrying capacity.

Like that from fin fish or shellfish farming, organic loading from seaweed aquaculture is an unavoidable effect. Small or large tissue particles will be torn off and whole individuals dislodged. Studies from Asia have suggested that organics corresponding to more than 50 % of the harvested biomass may be deposited on the sea floor as a consequence of seaweed farming. Recent studies from Europe suggest much lower figures, but also that these depend on the location, latitude, and the time of harvest. In other words: by correct management it is possible to minimise this organic loading and still retain a high biomass yield.

Researchers in GENIALG constructed mathematical models of coastal waters that suggest that dissolved nutrient concentrations are decreased, potentially on a large scale, by very intensive and extensive seaweed aquaculture. This may impact on the production of biomass by phytoplankton, which also require these compounds of nitrogen and phosphorus. If the coastal water is shared with shellfish farms, reduction in phytoplankton may lead to reduced shellfish production or food quality.

The amounts by which dissolved nutrient concentrations are reduced depend of course on the extent and the density of the seaweed aquaculture. However, faster water exchange between the farmed region and adjacent, non-farmed waters, and the potential for nutrient renewal from deeper waters (by upwelling or tidal mixing) may contribute to reduce the measurable impacts and increase both the production carrying capacity and the ecological carrying capacity. Mathematical modelling carried out in GENIALG, simulating the growth of kelp in several locations in northern Europe, suggests that naturally available nutrients can support production of at least 50 tonnes wet weight per hectare in well-flushed waters.

Other modelling suggests that large-scale kelp farming should be seen as competing with phytoplankton for nutrients. However, the main current concern about nutrients in coastal waters is that of eutrophication, the result of adding nutrients. Thus, decreases in dissolved nutrient concentrations are rarely seen as "problematic" by regulators, and the use of cultivated seaweeds to remove nutrients added by fin-fish farming, or agricultural drainage, may be seen as beneficial (as discussed in section 3.3).

Finally, the type of algae farmed needs to be taken into consideration. Green algae (e.g. *Ulva* species) differ from brown algae (e.g. *Saccharina latissima*) both in their ability to grow at low concentrations and in their yield of biomass from unit nutrient. These factors influence both algal productivity and nutrient depletion.

In summary, the maximum seaweed production in a given area depends on the type of seaweed, nutrient availability, water exchange and the type of region (enclosed bay, protected coast, exposed coast). It is therefore important to know as much as possible about the farming environment, as is the case for any other form of aquaculture.

3.2 Social Carrying Capacity

Social carrying capacity can be identified on two levels: 1) an operational/ site level and 2) the larger scale of society and its attitudes and laws. At a site level, determining the social carrying capacity involves understanding and engaging with local communities and other user groups to determine interactions with the aquaculture operation and the scale of operations that are deemed acceptable.

At a site scale, Social License to Operate (SLO) is increasingly being used as a tool for building positive operator-community relationships. Within the GENIALG project, the factors leading to SLO for seaweed cultivation were characterised. Across case studies in the EU, it was found that the social acceptability of a seaweed concession at a site level was often associated with:

- The scale/ size of the concessions;
- The levels of trust in the planning processes that local communities and environmental NGOs (eNGOs) had;
- The quality of engagement between communities, eNGOs and seaweed cultivators and;
- The measures that cultivators were taking to create positive industry-community relationships.

More information of SLO for seaweed cultivation can be found in Section 6. Although social carrying capacity assessments for aquaculture are still in their infancy, the basis of most assessments of social acceptability is effective, early, and ongoing engagement with local communities and user groups and understanding the local social and economic context of the area where an operation could be deployed. This enables operators to discern what negative and positive interactions they might come across, before applying for a concession and latterly how these interactions might change during the operation of a site. Critically, it allows for an operator to adapt to changing social scenarios, potentially reducing conflict, and developing mitigation strategies for any negative impacts identified, which are community and context appropriate.

On the broader scale of society as a whole, public attitudes can shape the governmental systems that regulate aquaculture operations. This can be through engaging with planning and licensing procedures, where many democracies have mechanisms for public consultation, or it can be through wider political engagement, carried out most effectively by trade associations that can inform the public and lobby governments.

3.3 Ecosystem services provided by seaweed farming

The obvious product of seaweed farming is of course seaweed, and much effort has been directed to finding markets for seaweed products that can bring monetary returns that are greater than the costs of farming and processing the algae. However, seaweed farming can also be presented, and valued, as an activity that improves the environment and is of additional value to human society. The extra value might come in the form of extra income to farmers or in good-will towards seaweed farming, the latter perhaps augmenting social carrying capacity. Therefore, it will be useful for seaweed farmers to consider how their activities can improve *ecosystem services* (as some call them) or *nature's benefits to people* (as others call them). Table 4 lists some of the ecosystem services that seaweed farming can provide.

As an example, a seaweed farm can provide the important *regulating service* of nutrient assimilation, with seaweed harvesting removing nutrients added to coastal waters by the farming of fin-fish, by agricultural run-off, or the discharge of urban waste water. In the case of *IMTA* as studied during GENIALG, *Ulva* cultivation removes fish-produced nutrients as well as providing a valuable product. Basin-scale *MTA* in which seaweeds are grown in the same water-body as a fish-farm, may allow a larger stock to be maintained at the fish-farm than would otherwise be the case. Finally, nitrogen credits – by which those discharging nitrogen compounds into natural waters would be charged per tonne, and the resulting monies used to pay seaweed farmers per tonne of nitrogen removed – are under consideration in some countries.

Data obtained by monitoring an experimental kelp farm operated in Ireland by the GENIALG project showed that the farm provided food and refuge for a diverse faunal community, including the role of nursery habitats for fish in the summer and shellfish (mussels, crabs) in summer and autumn. See section 5.3 in this manual.

Table 4 Ecosystem services that can be enhanced by seaweed farming and used to generate additional value

Service	Explanation	Valorization
Regulating: nutrient assimilation	Seaweeds can be used to remove nutrients from seawater	Co-cultivation in IMTA, collaboration with fish-farming in MTA, nitrogen credits
Regulating: carbon assimilation	Seaweed biomass can provide a source of renewable organic carbon (if substituted for fossil sources)	Carbon credits
Regulating: coastal protection	Kelp farming on long-lines can dampen waves	Requires investigation
Provisioning: fish nurseries	Seaweed farms may provide protective habitats for young fish	Requires investigation
Supporting: habitat protection	Seaweed farms of moderate intensity may help protect seabed habitats from human disturbance	Discuss with nature conservation agencies and NGOs
Cultural:	As marine farming develops, seaweed farms can provide educational and research resources and could provide positive cultural focus	Consult funding bodies and NGOs; aim to develop social licence

Thus, it is suggested that seaweed farmers should (a) consider which ecosystem services they can enhance with their farming, and (b) investigate national schemes for nitrogen credits, biodiversity maintenance, etc.

4 Biosecurity

Extensive monocultures provide ideal conditions for the development and spread of disease caused by micro-organisms. Seaweed farms need good biosecurity practices in order to minimise the disease risk. In addition, farmers and farming must avoid introducing alien genes to natural seaweed populations, alien species to natural ecosystems, and diseases that might spread to wild populations of seaweed.

4.1 Avoiding getting and spreading pests and diseases

A biosecurity plan should be written for both the hatchery and farm stage of any seaweed cultivation system. These should consider import/export routes, cross-contamination of cultures, monitoring of farm and cultures and treatment and disposal of wastes. Below is some general guidance which should not be interpreted as legal advice. Please check the laws/guidelines that are applicable for your site.

- **Import/export routes: Seedstock collection.** A defined protocol should exist for the collection of seedstock. Any equipment taken from the hatchery is clean/disinfected before transportation to any collection site. Any collected seedstock and equipment should be treated physically and/or chemically to limit, as far as possible, the import of pests or disease.
- **Import/export routes: Hatchery seawater.** Seawater brought into the hatchery, may carry pests and or disease lifestages. Typical seawater treatment involves filtration and UV sterilisation. Additional stages may be necessary depending on your specific situation: additional sand filtration, pasteurisation/Tyndalisation and autoclaving will be appropriate depending on circumstance.
- **Import/export routes: Farm site visits.** Any equipment transferred between locations (hatcheries/farm sites) should be clean/disinfected to prevent the accidental transfer of other organisms. For example, boats may need to be cleaned if visiting multiple spatially separate farm sites.
- **Import/export routes: Deployment of hatchery cultured seaweed to the farm site.** Hatchery grown seaweed, should be carefully examined and potentially treated before they are transferred to a deployment farm site.
- **Import/export routes: Moving cultured seaweed between farm sites.** Seaweed should not be transferred between sites, particularly open-sea locations, without a careful assessment of the risk of moving associated biofouling organisms, disease or juvenile stages of other organisms within the water column. This is believed to be the method by which ice-ice disease spread between globally separated cultivation areas of *Kappaphycus/Eucheuma* spp.

- **Cross-contamination of cultures.** Aseptic techniques, sterilisation of equipment, cleaning of facilities and adequate labelling should be used to ensure minimal opportunities for cross-contamination of cultures.
- **Monitoring of cultures.** Hatchery cultures should be examined regularly for contaminants and general health and condition. If contaminants, diseases or health decline is observed, action may be required to remedy this. It is recommended that the staff familiarise themselves with the abnormal appearance of diseased tissue (see Badis and Gachon 2017). Currently, there is no established reporting procedure for seaweed disease. It is recommended that seaweed farm operators have a research contact in the area of seaweed disease who may be able to analyse the sample further.
- **Monitoring of the farm: invasive species.** Country rules may require auditable monitoring and reporting of any invasive species in the area. Observations should be made of the farm structures whenever staff visit. Staff should be familiar with the appearance of any common invasive species and the reporting procedure.
- **Monitoring of the farm: Disease.** There are currently no rules for reporting disease occurrence. However, it is in all seaweed hatchery/farm operators best interests that research is undertaken to understand the occurrence and biology of any diseases. It is recommended that the staff familiarise themselves with the abnormal appearance of diseased tissue (see Badis and Gachon 2017). Currently, there is no established reporting procedure for seaweed disease. It is recommended that seaweed farm operators have a research contact in the area of seaweed disease who may be able to analyse the sample further.
- **Disposal of wastes: Hatchery seawater.** Waste seawater from a hatchery, should be treated before discharge to kill any pests or disease and prevent their export from the hatchery. Chemical treatment with hydrogen peroxide and ozone have been explored as options. The environmental implications of any discharge of treated water, must also be considered. Small volumes may be treated by autoclaving.
- **Disposal of wastes: Hatchery cultures and consumables**. Autoclaving is an appropriate method to ensure that waste cultures and consumables are made safe before disposal.
- **Disposal of wastes: Farm infrastructure**. Ropes, buoys, anchors etc, should be brought onto land and left exposed to the elements before re-deployment. This will kill all seawater organisms. Transferring infrastructure between sites could lead to unintentional movement of pests or disease.

4.2 Avoiding the introduction of alien genes and species

It is recommended that seed material be obtained from nearby and not transported more than 40 km, in order to avoid the introduction of allochthonous genetic material into natural seaweed communities. Care must be taken (and it is mandatory in some countries) to only farm native species to the coastal area where the farm is implemented.

4.3 Increase our current understanding of seaweed pathogens and pests

Seaweed diseases and pests are not well known. To help remedy this, GENIALG and the UK GlobalSeaweedSTAR have set-up a participative web portal called "My Seaweed Looks Weird" (short: MSLW; Fig. 8)). The portal is available in English, Spanish and Portuguese in order to reach out to a broad audience of scientists, farmers and "phycophilists".

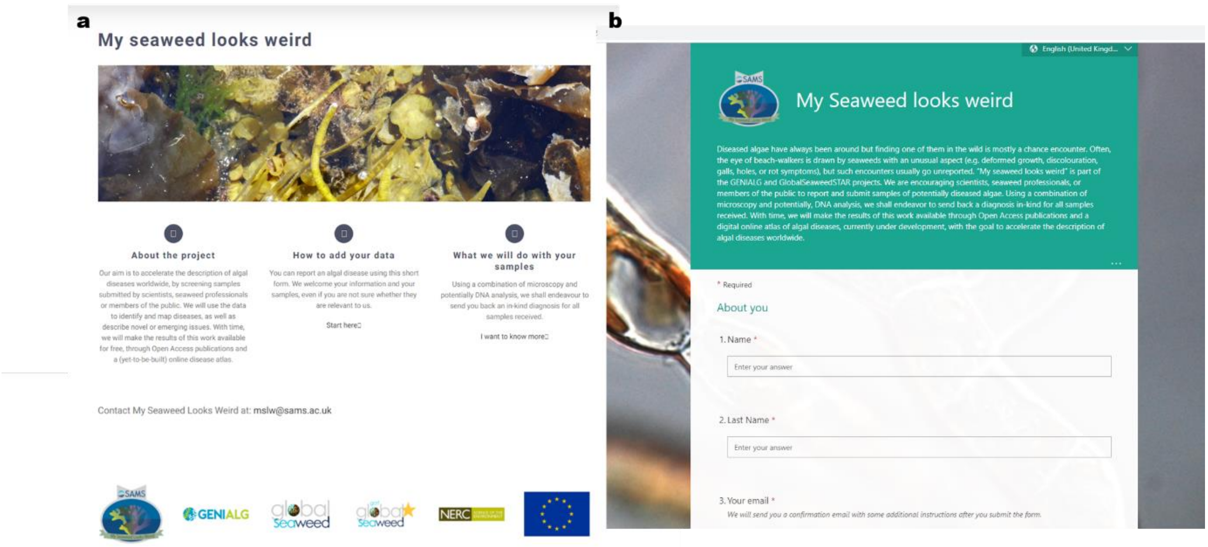


Figure 2 The MSLW online web portal.

a) Web-site https://globalseaweed.org/?page_id=889 explains submissions and sample analysis. b) the web-page *https://globalseaweed.org/?page_id=902* : an online questionnaire for submission of samples and observations.

The main objectives of this portal are to encourage worldwide submissions in form of observations, image material and / or physical samples of seaweeds with disease symptoms, either farmed or from wild individuals. Submissions in the form of physical samples are examined via microscopy and if possible, via molecular barcoding in order to identify possible algal pathogens and pest organisms.

The data, such as GPS coordinates, images, molecular taxonomic identification etc, obtained via the web portal (with agreement of the submitting person) are eventually included into an open-access Digital Atlas of Algal Diseases, currently being set-up (Figure 3). The atlas will contain taxonomic information about algal hosts and pathogens, images, references and biogeography data. It will be a resource that can be consulted for disease diagnostics and development of suitable biosecurity protocols.

Figure 3 The Online Digital Atlas of Algal Diseases.

This is currently under construction and accessible at http://algaldiseases.myspecies.info/

5 Environmental & Monitoring

5.1 Introduction

Seaweed-dominated ecosystems perform a number of functions, including provision and maintenance of biodiversity, primary and secondary productivity, carbon, oxygen and nutrient cycling, attenuation of acidification and water flow attenuation. Although scientists have reviewed the potential environmental interactions of seaweed aquaculture, there is a dearth of observational studies quantifying these interactions, especially in Europe. Thus, the environmental effects of seaweed farms need further study by scientists, regulators and farm managers. Whilst studies reported in peer-reviewed scientific journals tend to be expensive and detailed, designs for monitoring for management and regulatory purposes should be cost-efficient. Nevertheless, farmers need to know what impact farms have on their environment in order to avoid harmful feed-backs or damage to ecosystem services used by other sectors, even in cases when there is no regulatory requirement for monitoring.

Overall identification and quantification of potential environmental effects should focus on changes in hydrodynamic conditions, sediment transport patterns in and around the farm and potential changes in siltation rates, seafloor organic enrichment rates and light penetration that could affect benthic communities and primary producers (Fig. 4). The main issues to be considered in a monitoring program are described in table 5.

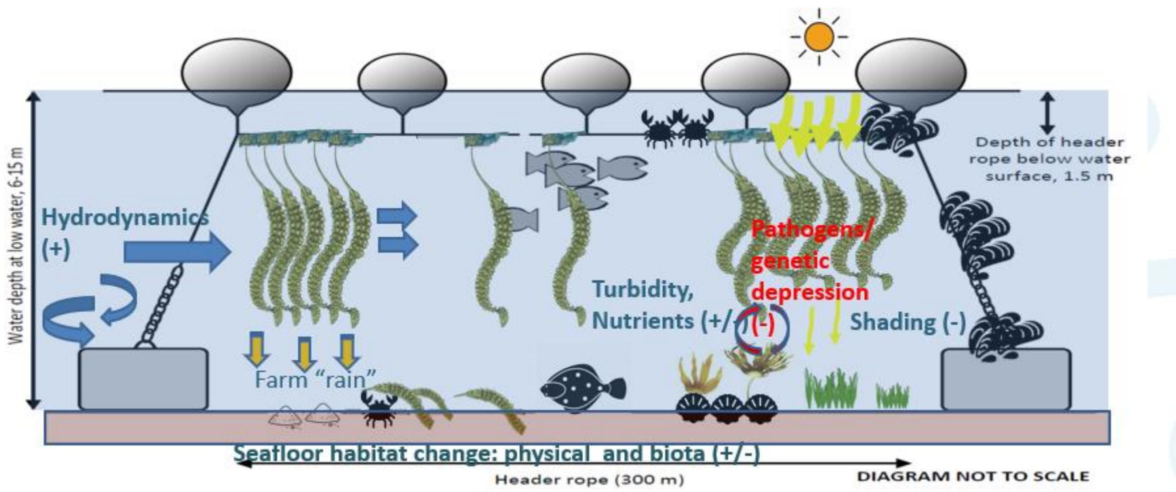


Figure 4 Schema of possible interactions between seaweed aquaculture sites and the environment. (Jose M. Fariñas-Franco).

Table 5 Potential positive and negative environmental effects arising from offshore seaweed cultivation

Environmental component	Effect	Consequences (+/-)
Physical environment	Nutrient and pollutant removal	Ameliorate eutrophication (+)
	Changes in wave and current patterns, energy absorption	Depending of location and local hydrodynamic patterns it could lead to: Coastal protection (+) Coastal erosion (-)
	Changes in sedimentation patterns	Increase water clarity (+): farms act as sediment traps Increase dissolved and particulate organic matter (+/-) Increase organic matter inputs to seabed (+/-)
Biotic environment	Cultivated seaweed act as keystone/foundation species	Essential habitat for commercial fish and shellfish species(+)
		Enhancing biodiversity (habitat creation and food opportunities) (+)
		Support of local food webs (+)
		Stepping stones for non-native species and pathogens (-)
	Ancillary structures act as artificial habitats	Enhancing biodiversity: provision of settlement substrate for epifauna (+).
		Development of associated community supporting fish, birds and other predators (+)
		Stepping stones for non-native species (-)
	Nutrient competition with primary producers	Changes in trophic webs, reduction in biodiversity (-)
	Light competition with benthic primary producers	Declines in extent and coverage Changes in benthic communities, reduction of benthic biodiversity (-)
	Physical disturbance from moorings and longlines	Abrasion, scouring, smothering, loss of habitat (-)
		Entanglement (-)

5.2 Recommended monitoring methodology

Monitoring needs to provide data that can distinguish natural variability from any potential changes, in the physical-chemical environment and in the biota, introduced by the presence and running of the seaweed farm. To that effect surveys should follow a modified *Before, After, Control and Impact* (BACI) approach to detect temporal trends and spatial gradients directly linked to the presence of the farm, with appropriate controls to differentiate natural or seasonal environmental dynamics. When investigating direct biophysical effects on the benthos, the survey design should capture spatial gradients using the farm as the source of any potential impacts. Figure 5 illustrates this for the case of a research study carried out during GENIALG.

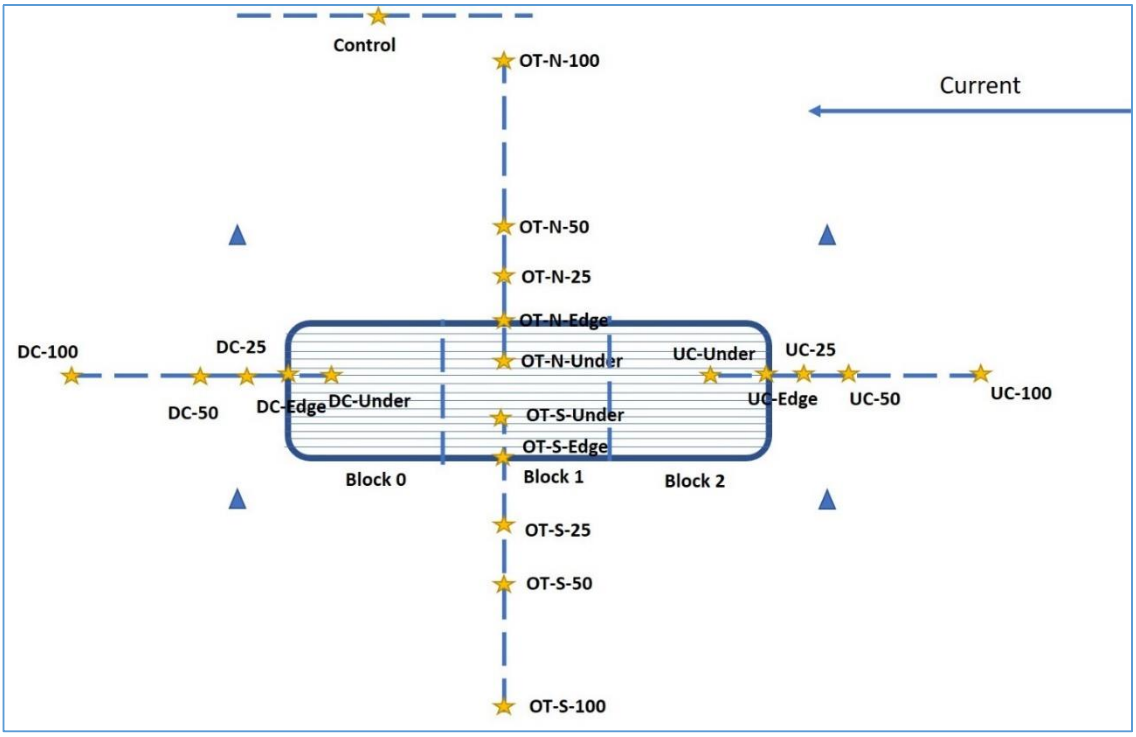


Figure 5 Schematic representation of the benthic survey design used during GENIALG

The design was used to monitor impacts from the test seaweed farm (mainly Alaria esculenta *on long-lines) located in Ventry Harbour, Ireland. The farm was 900 m x 200 m. Sampling stations represent grab sampling positions and video/quadrat transects, and are numbered to show distance in metres from the edge of the farm. The control site (for benthic surveys) was 200 metres from the farm edge.*

What should be monitored, and how frequently, depends on the size of farm and the resources available. However, as per BACI principles, data collection should ideally occur before the farming activities occur (pre-impact) and at least once every season during peak biomass and before deployment of seeded lines. The approach to monitoring could follow programs such as the 'survey, deploy and monitor' use in the licensing of marine developments in Scotland[1]. The level of monitoring under this policy is informed by three main factors, the environmental sensitivity of the proposed site, the scale of the development/farm, and the type of development (species and farm design in the case of aquaculture). The full environmental monitoring approached followed in GENIALG is described in Table 6: it can be adapted to satisfy regulatory requirements. Nonetheless, baseline surveys with adequate controls are crucial to detect the presence of habitat or species of high conservation value and identify subsequent impacts linked to the seaweed farm operations.

Table 6 Full environmental monitoring strategy for seaweed farms, as implemented during GENIALG

Environmental element targeted	Survey/sampling strategy	Approach	Description
Benthic habitat monitoring: baseline, peak biomass, post harvest	Dive surveys or remote imagery	Qualitative	Habitat surveys to detect sensitive, protected habitats of high conservation value (see Marine Monitoring Handbook by Davies et al. 2001)
			Initial habitat description to inform licensing and provide baseline data to inform the need of further monitoring.
	Dive surveys or remote imagery	Semi-quantitative	***Photoquadrats*** for colonial/turf taxa presence, extent and coverage: ***SACFOR score*** and ***EUNIS biotope assignation***. Calculation of ranked biodiversity indices
	In situ cores (diving) or remote grabs (small ***van Veen grabs*** deployed from vessel)	Quantitative	Identification and enumeration of ***infauna***l macroinvertebrate community.
Farms as habitat:	Deployment of "droppers": Full	Qualitative/Quantitative	Seeded and unseeded droppers collected every

[1] www.gov.scot/publications/marine-licensing-applications-and-guidance/ which includes the procedure for licensing an algal farm.

Environmental element targeted	Survey/sampling strategy	Approach	Description
Biodiversity and detection of non-native species and pathogens	Taxonomic ID of epifaunal community via classical methods or ***eDNA*** possible		3 months (see Figure 10 in FF 2021: it could be adapted to reduce replication and increase recovery times). Alternative settlement panels: ***epifaunal*** colonisation could be set-up and followed-up quarterly.
Farms as essential fish/crustacean habitat	Direct sampling of cultivated seaweed at 4 or 5 times during growing season	Quantitative	Seaweed growth estimations coupled with faunal community and ***stable isotope analysis*** to detect changes in local food webs. These samplings can also inform of ***epiphyte*** colonisation patterns as an early warning system to inform harvesting timings
	Visual census counts/BRUCs: peak biomass, post harvest.	Qualitative/quantitative	Diving along representative, replicate transects (30 m length of 5 minutes video) or deployment of baited cameras.
Abiotic monitoring	Data loggers: temperature, salinity, turbidity, chlorophyll and ***PAR***. Nutrients if possible.	Continuous recording, quantitative	Positioned under farm, on longlines and at distant controls
	Water sampling for nutrients (in absence of continuous data logging): ammonia, total nitrogen, phosphates; ***TSS***, ***POM*** and turbidity		Three replicates from below the surface and off the seabed bottom using a ***Niskin bottle***. Monthly or fortnightly monitoring during the season, within the farm and at control station at a minimum.
	Current meters (***ADCPs, aquadopps***)	Hydrodynamic and particle dispersion modelling (2-D/3-D)	Deployments over full tidal cycle

Environmental element targeted	Survey/sampling strategy	Approach	Description
			Pre-seeding, peak biomass, post harvest
	In situ cores (diving) or remote grabs (small ***van Veen grabs*** deployed from vessel)	Quantitative: baseline, peak biomass, post harvest	Sedimentology and organic matter content analyses.
	Deployment of sediment traps under farm and at distant controls	Quantitative: during growing season and post harvest	Description of siltation patterns and seabed organic loadings

5.3 Results from GENIALG project

The results of the baseline and operational monitoring surveys carried out at the GENIALG site in Ireland suggests that, a priori, seaweed farming does not exert a negative influence on its surrounding environment but rather provide positive ecosystem interactions. For example, the results from these surveys showed any potential shading on primary producers is compensated by the farm acting as a sediment trap, as indicated by the higher water clarity and irradiance values within and under the farm compared to distant controls. The reduction in turbidity was also matched by a reduction in silt deposition, with sediment traps yielding higher volumes of silt deposited on the seabed outside the farm compared to under it. The facilitating of the conservation of benthic habitats of high conservation value, e.g. seagrass, through the provision of de-facto protection against physical disturbance from anchoring or bottom trawling is also likely responsible for the significantly higher abundance and coverage of seagrass under the farm and thus identified as possible positive interactions. Overall, benthic monitoring, at the temporal and spatial scales considered, showed the farm had no negative impacts and that variability in organic carbon and sediment composition was natural. Longline surveys in Ventry also confirmed the use of cultivated seaweed as nursery grounds for fish species (e.g. *Pollachius pollachius*, *Gobiusculus flavescens*, *Cyclopterus lumpus*) possibly attracted by the high abundances of macrofauna, especially the amphipod *Jassa falcata* and the non-native ghost shrimp *Caprella mutica*, during the seaweed growing season. When the seaweed has been harvested or has decayed, the faunal assemblage shifts to that of a mussel-centered habitat type that is used as a nursery habitat for commercially important shellfish species, e.g. edible crab *Cancer pagurus*.

6 Social licence

THE Genialg project found evidence from Scotland and France, that user conflict and spatial issues will arise as the seaweed cultivation industry expands and the scale of farms increases. Identifying steps to develop positive relationships between communities and operators can improve social acceptability, reduce conflict and objections within the planning process, increase opportunities for collaborations, and increase the credibility of any down-stream products. In short, can lead to the acquisition of Social License to Operate (SLO). SLO can be described as an on-going relationship between a local community and communities of interest and an organisation (industry, NGO, business) where the organisation is held to certain standards set by the communities, in exchange for the trust and support of the communities. Getting and maintaining SLO can improve the viability of an operation through informal processes such as word of mouth and grass roots campaigns, and formal processes such as legislation and voluntary industry standards. Having SLO can protect the reputational capital of an industry from hostile campaigns, legislative action, and negative media portrayals. This can affect the base cost of producing the commodity, and/or the end price of the commodity for consumers, as well as the space available for expansion of operations.

Key Social License Measures

There are several aspects that have been found to increase the likelihood of developing social license to operate across marine and land-based sectors, including aquaculture. When combined, many of them reinforce each other in a positive feedback loop.

These factors include:

- ✓ Understanding the social context of the local area,
- ✓ the development of trust between developers/ operators and local communities/ communities of interest,
- ✓ quality contact, engagement, and effective communication,
- ✓ procedural fairness and consistency (both in developer decision-making and local governance systems),
- ✓ relationship-building activities including collaboration and community benefits,
- ✓ awareness of, transparency around and effective mitigation for perceived and measured negative visual and environmental impacts and,
- ✓ maintaining local social order or taking a gradual approach to changes in close collaboration with local communities and communities of interest.

The seaweed cultivation industry in the EU/ North Atlantic is currently in a good position, where general perceptions of cultivation are positive, however maintaining this position will require using many if not all of the key social license measures. The following points should be considered:

- **Low(er) environmental impact does not reduce likelihood for social opposition:** although current evidence on the environmental impacts of seaweed cultivation in the EU/ North Atlantic, suggests that it has a smaller environmental footprint than some other forms of aquaculture, this does not mean that SLO for an operation will automatically be granted. It would therefore be advantageous for the industry in the EU/ North Atlantic to work together where possible, to take a to research and address environmental impacts, as well as reporting on them in a transparent manner as they are often at the forefront of social opposition. Lessons can be learned from other aquaculture industries, where positive opinions have turned negative due to both real and perceived environmental impacts and the responses that the operators had to them.
- **Scale:** smaller scale operations are more likely to be granted SLO than larger operations. This is related to the risk appetite of local communities and communities of interest, where smaller scale operations can be perceived as inherently less risky in terms of environmental interactions, impacts on other users of the sea, and maintaining local social norms. Nevertheless, small-scale operators are advised to adopt some of the more cost-effective social license measures, such as good communication and collaboration (where feasible) with other local organisations.

  Larger operations are often perceived as inherently riskier to local communities and communities of interest. It is advisable that developers and operators at this scale adopt a more formal social license strategy. This could include ensuring that channels of communication are contextually appropriate, easily accessible, and requestions for information or action are responded to with sensitivity and in a timely manner. Having a local representative who has the power to report on feedback from the local community and request changes to operations, has been shown to improve community-developer relationships, and reduce the likelihood of outright opposition to larger operations. Opposition to initial proposals may be reduced or entirely removed through negotiation with local communities and compromise on the scale of the site.
- **Ownership models and accountability:** who owns seaweed cultivation operations is important to local communities and communities of interest. The greater the geographical distance between those who own the operations and the communities that host them, the more likely stakeholders are to perceive that decisions are not being made with the communities' best interests in mind or are made with a lack of understanding of the context of the local area. Further, national or multinational ownership models can be perceived decreasing the ability for communities and local business owners (especially other marine businesses located close to the site) to hold the operators accountable when something does go wrong (e.g. due to weather event). Adopting the measures previously described in this section can help to improve the likelihood for SLO for large-scale and distantly-owned operations.

- **Context:** it is crucial to understand the social and cultural context of an area where a site is being considered. Doing so will help developers ensure that communication, community benefits, work patterns, and working structures are appropriate and more importantly will not cause otherwise unnecessary social opposition. National and multi-national companies should consider local social and cultural context within any site selection and scoping studies and may want to either spend time on the ground engaging with local people and businesses, or better still, commission a local representative to conduct this work. It is still advisable for small-scale locally owned companies to ensure that they know the social context of their site (especially the other users in the area, including any land-based uses overlooking the site), in order to avoid otherwise solvable issues (such as ensuring locally-used navigation routes are maintained or mitigated for, or to reduce the likelihood of conflict with fishers, or breaches of indigenous rights).
- **Information and communication:** how and by whom information is communicated is a complex issue, dependent on context. It is almost always beneficial to use local representatives who know the local communities and understand the context of the area. Communication should be timely, efficient, accessible and correct, and should include transparent descriptions of both positive and negative social, economic and environmental interactions of the operations. Communication should also flow from the communities to the developers/ operators and where actions are requested, developers/ operators should do their best to seriously consider making these changes and provide feedback to communities on their decision, and how it was made.
- **Perceptions of bias in evidence:** In some instances, NGOs and local community groups can view scientific evidence commissioned by government, as biased towards the industry and hence less trust-worthy. This is particularly the case where there are top-down policies which are actively promoting the development of aquaculture (e.g. the Blue Agenda in the EU). Awareness of such perceptions is critical to addressing concerns effectively and with empathy, as producing scientific evidence does not necessarily mean there cannot be debates around its merits. This links to the previous point, where the organisation or individuals delivering the information and the form of its delivery can be as important as the information itself. Developing positive relationships with local communities and communities of interest can help improve discussions on the merits of relevant scientific evidence.
- **Keep it up**: SLO measures are not time-limited and should be maintained throughout the scoping, commissioning, operation, and decommissioning of a larger scale seaweed farm.

Table 7 Further resources for Social License implementation.

Further resources	
Topic	**Location**
Handbook on Social License for Seaweed Cultivation	https://www.sams.ac.uk/science/projects/genialg/
The Social License: How to Keep Your Organisation Legitimate	Morrisson, J. (2014). The Social License: How to Keep Your Organisation Legitimate. Palgrave Macmillan. ISBN 978-1-137-37072-3

7 Harvesting, storage and food safety issues

7.1 Harvesting and storage

Cultivated seaweeds need to be harvested in ways that are cost-effective, safe for operatives, minimise environmental impact, and preserve product quality. After they have been harvested, they may need to be stored before processing and/or shipping, and this raises issues about cost-effectiveness, energy-efficiency, and product quality and health. A variety of methods has been developed; their use depends on which characteristic/s of the seaweed are valuable for the end use of the material. Three cases are identified:

1. To be eaten fresh. In this case the seaweed must be kept alive within, their sometimes highly restrictive physiological tolerances, whilst retaining favourable ***organoleptic*** characteristics such as texture, smell and taste. This end-use requires only short term storage from a few days in refrigerator or on ice (7 days) but also gives opportunities for storage in weeks in cold, running seawater, alternatively temperatures suitable for the given seaweed species. Another method is preservation in seasalt (solid brine) which allows for storage up to 12 months, method used presently for large scale trading.

2. Stored for longer-term, while retaining maximal quantities of easily degraded chemical constituents. This case encompasses their use as a) highly nutritious food ingredients, where a long shelf life is desired, and favourable organoleptic characteristics must also be maintained or b) for the extraction of refined ***bioactives***. In this case, the seaweed will be stored in stable conditions to limit any changes to the biomass. Drying is the most used method – the most common way of trading seaweed is dried - and there are several possible ways for drying of relevance, including sun drying, solar drying, freeze drying, oven drying, spray drying or use of different types of drying cabinets. According to the drying procedure, shelf life may be up to 3 years. Freezing and storage at -20°C, preferably after vacuum-packaging, is also convenient for these applications.

3. Stored in volume for large scale industrial processing such as the bulk extraction of chemicals e.g. ***hydrocolloids***, use in animal feeds or biofuels. In this case, only a very few sensory and chemical characteristics of the biomass are important to the final product, whereas high throughput processing and cheap storage are essential to allow business profitability. Therefore, the processing is often low-tech or quite aggressive, causing considerable degradation of the biomass compared to in 1 or 2. Processing not only varies with end-use, but also depending on the species and the scale and technicity of the operation. For large

scale storage the less energy consuming methods of ensilage and chemical preservation are preferred.

7.2 Safety standards for Seaweed

Quality and safety standards for seaweed and microalgae to be applied in Food and Non-Food uses are being discussed in Europe by CEN-TG454 Algae and algae products. It is expected that after that work is finished, EU standards can be applied to all countries, thus fostering a stronger and more unified development of the sector.

Depending on where they are grown, seaweeds can accumulate elements from seawater in excess of desirable levels. This section concerns **heavy metals** and iodine.

The maximum permitted heavy metal limit s for algae are not often listed in legislation. France is ahead of the game and its High Council of Public Hygiene (CSHP) has been publishing criteria for heavy metals and iodine since the 1990s, to guarantee the absence of toxicity of these foodstuffs and thus promote the development of the sector. The European Union has published a recommendation on the monitoring of metals and iodine in seaweed, salt-tolerant plants and seaweed products for 3 years, starting in 2018. Concentration limits for metals have been set for seaweed-based additives. In the case of cadmium, a limit for food supplements composed exclusively or mainly of dried seaweed and seaweed products has been defined. For iodine the limits are also defined by the Food Standards Code of Australia and New Zealand, as well as for France.

The maximum levels are summarised in Table 8.

Table 8 Maximum levels of heavy metals in foodstuffs (or food additive) derived from algae.

The levels are set in mg/kg, or parts per million, according to the legislation of each country.

Elements	Europe	France	Australia and NZ	USA	Europe Additive food
Inorganic Arsenic		3.0	1.0	3.0	
Arsenic total					3.0[3]
Cadmium	3.0 [1]	0,5			1,0 [4] 2,0 [5]
Mercury		0,1			1,0[3]
Lead		5,0		10	2,0[2] 5,0[3]
Tin		5,0			

Elements	Europe	France	Australia and NZ	USA	Europe Additive food
Heavy metals (total)				40	
Iodine		2000	1000	5000	

[1] Food supplements composed exclusively or mainly of dried seaweed, seaweed products or dried bivalve molluscs.

[2] algae additive: algae carotenes

[3] Algae additive: alginic acid, agar agar, carrageenan, processed euchema seaweed (same maximum values for As, Hg and Pb)

[4] Algae additive: alginic acid, agar agar (Cd value=1)

[5] Algae additive: carrageenan, processed eucheuma algae (Cd value = 2)

8 Conclusions/General recommendations

Seaweed aquaculture is a new activity in Europe and substantial research and work is still needed to make it a mainstream activity, with all the correct rules, regulations and standards that will help the industry thrive in a sustainable way. There is a danger that, without data to inform policy, regulators will develop overzealous monitoring and licensing legislation, and thus lay additional burden on the farmers and investors. In order to remedy the data gaps, the best approach would seem to involve partnerships between industry and academia in order to develop further the best practices that have been sketched in this document for monitoring and for determining environmental and social carrying capacities. As we have documented, well-designed monitoring programmes can, additionally, detect and quantify the ecosystem services that well-designed farms can enrich. These can include biodiversity enhancement, protection of natural habitats, and acting as carbon sinks and as nursery habitats for commercial species. Thus, the development of systems of biodiversity or carbon/nutrient credits or payments could help steer the development of environmentally-responsible seaweed farming as well as help the balance sheet of farms. Making environmental monitoring a requirement in the seaweed aquaculture licensing process could be a very valuable exercise not just to minimise the risks highlighted in this document but to provide site specific observational data on the biophysical footprint of seaweed farms that can be used to claim ecosystem services provided by the farm as well as to increase social acceptance and support the expansion of the industry.

9 Further reading

This section lists scientific papers, reports and books that have been drawn on for this manual, and which provide more detailed information than given in the preceding pages.

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10 Glossary

***ADCP**: Acoustic Doppler Current Profiler:* an instrument that measures water currents with sound. The ADCP transmits sound pulses that reflect on particles suspended in moving water currents. The instrument uses the differences in frequencies between the emitted and reflected pulses to calculate water speed and direction. Data from ADCPs and other current meters are used to calibrate hydrodynamic models. Commercial models include Nortek's AWAC and Aquadopp

alga: (plural, *algae*) any organism that can photosynthesize and is not a land plant or a bacterium; includes green, red and brown seaweeds and many kinds of single-celled micro-algae found in the plankton;

alternation of generations: a common life-cycle amongst algae, involving a diploid sporophyte stage that produces haploid spores giving rise to a generation of gametophytes, which produce eggs and sperm that combine to give rise to the next generation of sporophytes; in the sugar kelp the gametophyte stage is small and the sporophyte large; in the sea-lettuce, the two stages are almost identical;

***BACI**: Before, After, Control and Impact* – recommend monitoring strategy*;*

***bioactives**:* a compound that has a effect on a living organism, tissue or cell; usually distinguished from essential nutrients; typical bioactives extracted from seaweeds include carotenoid pigments;

Chlorophyta: a high-level taxonomic category of green algae including green seaweeds such as *Ulva* and small green micro-algae; they are related (perhaps ancestral to) land plants;

community: (social science) a group of intercommunicating people living in the same place or sharing a common interest, and having accumulated mutual knowledge of, and trust in, each other; (natural science) the set of populations of organisms found in a habitat;

diploid: containing two sets of chromosomes, and hence 2 copies of most genes, in each cell;

***ecosystem services*: **exports from ecosystems to human economies that, combined with human financial, physical, intellectual and social capitals, bring benefits to the people in these economies; the Millennium Ecosystem Assessment distinguished supporting, regulating, provisioning and cultural services; an example regulating service than can become a benefit is an aquatic ecosystem's ability to assimilate nutrient waste from fish-farms. agricultural run-off, or urban waste-water disposal; the argument for identifying monetary values for ecosystem services is that, in a market economy, the incorporation of their costs and benefits can lead to more environmentally sustainable human activities;

***eDNA**: Environmental DNA*, DNA collected from environmental samples e.g. seawater, used to detect the presence of marine organisms and estimate their diversity in the environment. Sources of eDNA in samples include faeces, tissues, or mucus.

***epifauna**:* the community of animals that live on (as opposed to within) seabeds: e.g. barnacles or sponges, found on hard surfaces.

***epiphyte**:* an animal, alga or micro-organism that lives on a plant or seaweed

EUNIS: European Nature Information System. An EU information system that provides access to publicly available biodiversity data. The EUNIS habitat classification system is a standardised, pan-European hierarchical system for marine and terrestrial habitat classification – see https://eunis.eea.europa.eu/index.jsp

facilitator: a person whose role is to encourage communication in a stakeholder engagement meeting; they should be neutral with respect to the interests of developer and stakeholders and able to win the trust of both; they should not seek to arbitrate or to resolve contrary positions, only to allow those positions to be politely expressed;

gametophyte: the haploid stage in alternation of generations, producing sexually active cells (often, eggs and sperm) that combine to form a diploid zygote, the first cell of the sporophyte generation;

haploid: containing only a single set of chromosomes and genes in each cell;

hydrocolloid: a jelly or gum, including alginates (extracted from brown seaweeds) and carrageenans (extracted from red seaweeds), which strongly absorb water, used in wound dressings and as thickening agents in food;

IMTA: *Integrated MultiTrophic Aquaculture*, the co-cultivation of organisms at different trophic levels (for example, seaweed and fish) in the same facility;

Infauna: the community of animals that live within soft sediment sea-beds; for example, clams, lugworms.

MTA: *MultiTrophic Aquaculture*, the cultivation of organisms at different trophic levels (for example, seaweed and fish) in the same water-body but not necessarily at the same site;

nature's contributions to people: a reframing of the *ecosystem services* concept, with more emphasis on non-monetary values and the role that culture plays in defining links between nature and people;

Niskin bottle: a device used to collect water samples at different depths in the water column. It is made of plastic and cylinder-shaped, with stoppers at each that can be remotely closed mechanically (using 'messengers') or electronically at the required depth. They can be used individually or set up in carrousels of several bottles to collect samples at different depths in the same deployment.

nitrate(s): dissolved salts containing nitrogen and oxygen, essential nutrients for plants and seaweeds, formed in the sea when bacteria oxidise ammonia excreted by animals, or input from human sources in sewage or contamination of waters by agricultural fertilisers;

organoleptic: a property perceptible to one or more senses (sight, taste, small and touch);

PAR: *Photosynthetically Active Radiation*. Refers to the fraction of daylight available to a primary producer for photosynthesis, i.e. light in the 400-700 nm wavelength range.

Phaeophyceae: the class of brown seaweeds, related to many types of yellow and brown micro-algae, but as distinct from the green algae as both groups are from animals.

phosphate(s): dissolved salts containing phosphorus and oxygen, essential nutrients for plants and seaweeds, added to seawater in animal excreta, or input from human sources in sewage or contamination of waters by agricultural fertilisers

photoquadrat(s): photographs of a standardised reference area delimited by a quadrat. A quadrat is a frame, usually square, made of metal or plastic. They are used in ecological studies to estimate abundance or coverage by animals and plants over a substrate, e.g. seagrass abundance on the seafloor.

POM: Particulate Organic Matter;

regulating service: within the ecosystem services framework, regulating services are those that maintain ecosystem functions of value to humans when these are perturbed by local human activities (such as fish-farming or urban waste-water discharge) or by larger-scale disturbances such as those due to natural and anthropogenic climate change;

SACFOR: unified system for recording abundance of marine fauna and flora developed by the Marine Nature Conservation Review (MNCR). It converts quantitative values (e.g. densities and percentage cover) into semi-quantitative scores: *Superabundant, Abundant, Common, Frequent, Occasional, and Rare*. See: https://mhc.jncc.gov.uk/media/1009/sacfor.pdf

species: one or more interbreeding populations of organisms with similar characteristics that can be distinguished from those of other species

sporophyte: the diploid stage in alternation of generations, producing haploid spores by meiosis (chromosome-reduction) that give rise to the gametophyte generation;

stable isotope analysis: the analysis of samples of tissue, using e.g. a mass spectrometer, to determine the ratio of (non-radioactive) isotopes of one or more elements -- for example Carbon13:Carbon-12 or Nitrogen-5:Nitrogen-14 – with the aim of identifying the source of the element(s) in the tissue;

stakeholder: an individual or an organisation with a legitimate interest in an activity or its consequences;

stakeholder mapping: an exercise aimed at identifying stakeholders, and their interests, in relation to a proposed or existing activity;

strain: a population of organisms with identical genes; note the problem of maintaining a strain through the recombinatory sexual act producing sporophytes;

TSS: *Total Suspended Solids*

van Veen grab: an instrument used to collect samples of seafloor sediments, i.e. a grab sampler. It consists of a clamshell bucket of varying sizes usually made of stainless steel.