GENetic diversity exploitation for Innovative macro-AlGal biorefinery

Deliverable 6.5

Socio and ecological impacts of seaweed cultures (cost-benefit together with WP5 and societal acceptability together with WP7)

Planned delivery date: September 2020

Actual submission date: July 2021

Work Package: WP6

Work Package Leader: CIIMAR

Deliverable Leader: DLO

Version: 1.0

Start date of the project: January 1st, 2017

Project co-funded by the European Commission within the Horizon 2020 Programme (2014-2020)	
Dissemination Level	
PU Public	X
CI Classified, as referred to Commission Decision 2001/844/EC	
CO Confidential, only for members of the consortium (including the Commission Services)	

contribution to people and the business case for cultivation

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Abstract

Seaweeds (macroalgae) are heralded as source of food, feed and biobased materials, needed to provide a growing and more affluent world population with sufficient biomass. At the same time, seaweed aquaculture is considered as one of the most sustainable forms of protein production, delivering various nature based solutions (ecosystem services) to the surrounding ecosystem. European seaweed producers have for these reasons sought to apply number of so-called upgrading strategies, seeking to increase the value of their product. The analysis provided below combines quantitative data and qualitative data, collected from literature review and the studies conducted in the GENIALG project. A techno-economic model was developed to evaluate the financial viability of seaweed production in Europe, from hatchery to farming, pre-processing and processing. Despite the vast literature on values of ecosystem services, there exists no commercial value for the majority of supporting, regulating and cultural ecosystem services on the market to date. Profitable seaweed cultivation requires targeting higher value markets that can pay higher prices for raw material. The valuation and monetarisation of ecosystem services might then provide additional sources of income.

Key-words

Macro-algae, ecosystem services, carbon sequestration, payment for ecosystem services, nutrient trading

1. Introduction

Seaweeds (macroalgae) are heralded as source of food, feed and biobased materials, needed to provide a growing and more affluent world population with sufficient biomass. Various studies and research projects have confirmed that it is possible to cultivate seaweeds in Europe, in land-based, near-shore and open ocean conditions (Jansen et al. 2016; Stévant, Rebours, and Chapman 2017; Hasselström et al. 2020). Cultivation of seaweeds is also expected to make a positive contribution to the local environmental conditions, local biodiversity and bioremediation of pollutants (Elizondo-González et al. 2018; Kroon, Schaffelke, and Bartley 2014; Cabral et al. 2016). Despite all these promises of seaweed, large-scale cultivation of seaweeds in Europe is yet to take off. Barriers to large-scale cultivation include uncertainty about the future market development, the food safety risks (Banach, Hoek-van den Hil, and der Fels-Klerx 2020) and the costs of production which are currently higher than world averages (van den Burg et al. 2016).

European seaweed producers have for these reasons sought to apply number of so-called upgrading strategies, seeking to increase the value of their produce (Gereffi and Fernandez-Stark 2016). Next to more traditional upgrading strategies, such as emphasizing product quality and product safety albeit in combination with certification, or targeting high value markets (Selnes, Giesbers, and van den Burg 2021), there is increasing interest in acknowledging and capitalizing on the value of ecosystem services and Nature's Contribution to People (NCP) provided during seaweed cultivation. Recognizing and valuing those benefits might spur the transition to a seaweed based economy, if accompanied by suitable financial instruments.

Nature's contributions to people (NCP) are all the contributions, both positive and negative, of living nature (i.e. diversity of organisms, ecosystems, and their associated ecological and evolutionary processes) to the quality of life for people[1]. NCP promises a more holistic framework to assess what nature brings to humankind. The concept does include ecosystem services, defined as the benefits people obtain from ecosystems. In the Millennium Ecosystem Assessment, ecosystem services can be divided into supporting, regulating, provisioning and cultural.[2] Throughout this paper, we use the term ecosystem services, being more frequently discussed over the last years.

The contribution of marine resources to circular systems in terms of food production (provisioning services) is well quantified through stock assessments, sustainable harvest targets and associated market values. Less well quantified are the ecosystem services that can assist in improving the circularity and nature-inclusive production potential. While there has been a considerable amount of literature on valuing ecosystem services and natural capital (Costanza et al. 1997, Barbier et al. 2011, Grabowski et al. 2012, de Groot et al. 2012, Kim et al. 2015, Pendleton et al. 2016), the values for biomass and ecosystem services can vary extensively from study to study. This is in part due to the nature of evaluating ecosystem services at the marginal value which is location, base level and time-period or dependency specific (Rönnbäck et al. 2007, Barbier et al. 2011, Grabowski et al. 2012). For example, as economic growth accelerates for developing countries, the marginal value of ecosystem goods and services will change, with the derived uses evolving from subsistence fishing to the production of higher-end goods and services (e.g. pharmaceuticals, tourism) and the perceived non-use values (e.g. existence or bequest value) increasing as individual wealth and willingness to pay increase (Rönnbäck et al. 2007). Equally true is the concept of diminishing returns to the value of ecosystem services as the base existing level of service grow, or as biodiversity is restored (de Groot et al. 2012, Grabowski et al. 2012).

The objective of this paper is to evaluate if and how the inclusion of seaweed's ecosystem services, being "seaweed's contribution to people" in the business case can spur seaweed farming in Europe. This requires addressing the following sub-questions

- What is the current and expected economic performance of seaweed production in Europe (see section 3)

[1] https://www.ipbes.net/glossary/natures-contributions-people
[2] https://ipbes.net/glossary/ecosystem-services

- What is Seaweed's Contribution to People, provided during seaweed cultivation, including assessment of the economic value of such benefits? (see section 4)
- What is the viability of carbon and nutrients trading and payment for ecosystem services as avenues for capitalization (see section 5)
- What is needed for capitalization of ecosystem services to support the growth of the European seaweed sector? (see section 6)

The analysis provided below combines quantitative data and qualitative data, collected from literature review and the studies conducted in the GENIALG project.[3] Results can be used in further discussion on development of the European seaweed sector and in discussion on advancing payment of ecosystem services. The study focusses on the production of Saccharina latissima in European waters.

2. Methods

Economic model

A techno-economic model was developed to provide the user with a rough assessment on the financial viability of operation for a hatchery, farm and/or processing facility, using the Excel add-on @RISK. The model evaluates the alternative scenario against the current baseline reported by the simple model. Uncertainty is capture through 1,000 iterations of Monte Carlo simulation. This allows the user to view not only a single estimate based on the result of the iterations, but also the full distribution of possible output values for production costs at each segment of the operation. Moreover, the assessed probabilities of generating a negative profit for the production and processing segments are also provided.

The input used in the techno-economic models for *Saccharina latissima* are sourced from industry participants in the GENIALG project. Information provided include financial operating data under a potential future/expected scenario of production for a hatchery, farm, pre-processing and processing facility. It should be noted that the data is actually an amalgamation of two distinct value chains in Europe at the present time, each targeting a different market. Pre-processing (i.e. the practice of washing, cleaning and storing seaweed) marks one of the final steps in the value chain of preparing *Saccharina latissima* destined for human consumption. In contrast, processing activities reflect the current mechanical means of producing alginic acid using *Saccharina latissima* harvested from the wild.

Given the two distinct value chains and their respective end-markets, there were several issues with the data inputs for the model. The first is the mismatch in use of *Saccharina latissima* across segments of the production chain. Production up to and including pre-processing targeted the market for human consumption, and could therefore fetch a higher price than the lower grade *Saccharina latissima* harvested from the wild that is used in alginate production. This caused issues in price transferability from farm output to raw material input required for processing. To address the problem in price transferability, the processing data collected was subsequently tailored to assess the breakeven condition for a hypothetical product in which the final output price would be high enough to justify the processing farmed *Saccharina latissima* by means similar to that for alginic acid. That is, the assessment looks at how high the output price would need to be for a hypothetical final high-end product, which requires similar costs of production as alginic acid, for the processing of cultivated seaweed to be financially viable in Europe.

[3] https://genialgproject.eu/

The second difficulty encountered with the data collected was the scale of production. For the hatchery, farm and pre-processing segments currently producing *Saccharina latissima* destined for human consumption, the output volume represents only a small fraction of the input materials needed in the processing segment under both the current and future/expected scenario. This means that utilising the data collect as it was would skew the financial results to the segment (i.e. processing) with the highest volume of production. To get around this issue and ensure confidentiality, financial data collected from all segments were standardised to a benchmark volume of 10,000 tonnes farmed output. That is, financial data collected for the hatchery was scaled up to ensure an output of sporelings that could generate 10,000 tonnes of farmed *Saccharina latissima*. In contrast, data for the processing segment was scaled down such that the production of final output matched a required input amount of 10,000 tonnes of farmed seaweed.

Ecosystem services

Identification of ecosystem services, as indicator for seaweed contribution to people, and possible avenues for capitalization was done through literature research. Both Scopus and Google Scholar were used for retrieving data. The snowballing method was used to identify relevant publications.

3. Expected economic performance

The @RISK based model focuses primarily on the probability of financial outcomes for the alternative scenario than making comparisons to the current state. As such, results produced are centred around probability distributions and likelihoods of reaching a particular outcome. Table 1 displayes the summary statistics of the probability distribution for the final economic parameters of *Saccharina latissima* production and processing in Europe under the alternative scenario. Figure 1 provides the visual illustration for the last parameter in the table, revenue less cost after processing (i.e. operating profit).

Table 1: summary statistics of economic parameters for total activities in all segments of the production chain for Saccharina latissima in Europe under the alternative scenario

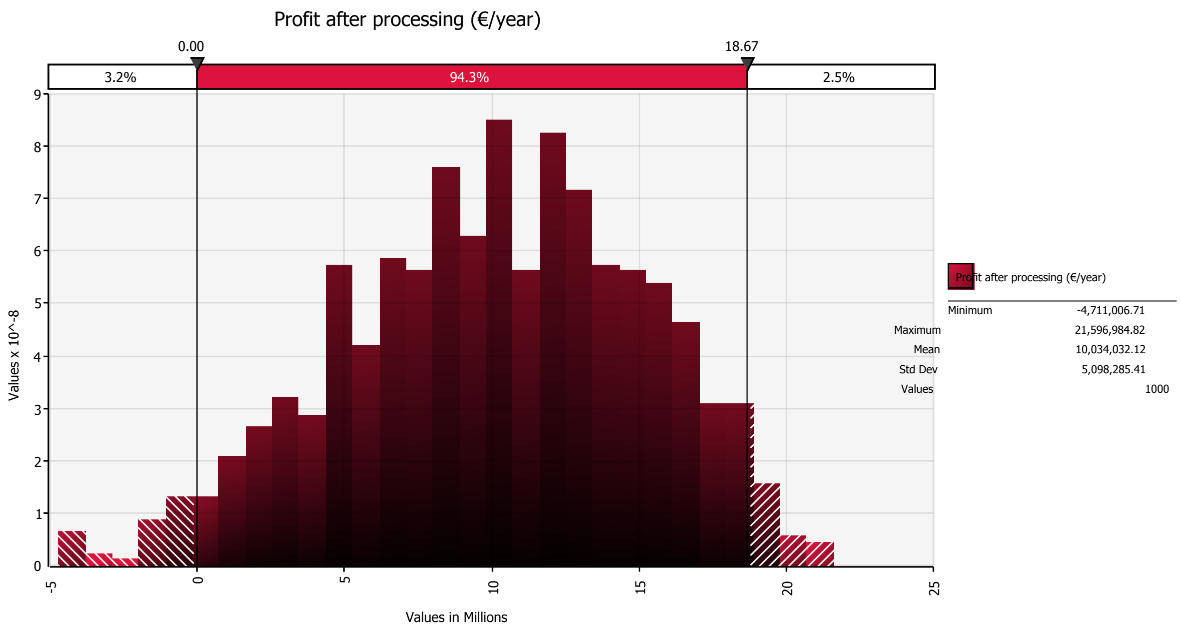
Economic parameters	***Mean***	***2.5% CI***	***97.5% CI***	***St. dev***	***P (profit ≤ 0)***	***Measure***
Total production and processing costs	24,513,316	22,375,885	26,670,037	1,124,600		€ / year
Total revenue after processing	34,547,348	24,490,575	42,869,181	4,975,358		€ / year
Revenue-costs after processing	10,034,032	-482,820	18,674,913	5,098,285	**3.2%**	€ / year

The results in Table 1 can be interpreted as:

- The total average cost of production and processing for *Saccharina latissima* in Europe across all segments of the production chain under the alternative scenario is estimated at €24,513,316 based on 1,000 iterations of Monte Carlo simulation (at a benchmark volume of 10.000 tonnes of farmed seaweed). The 2.5% and 97.5% confidence interval (CI) bounds suggest that 95% of the iterations generated a value for total production and processing cost between €22,375,885 and €26,670,037.

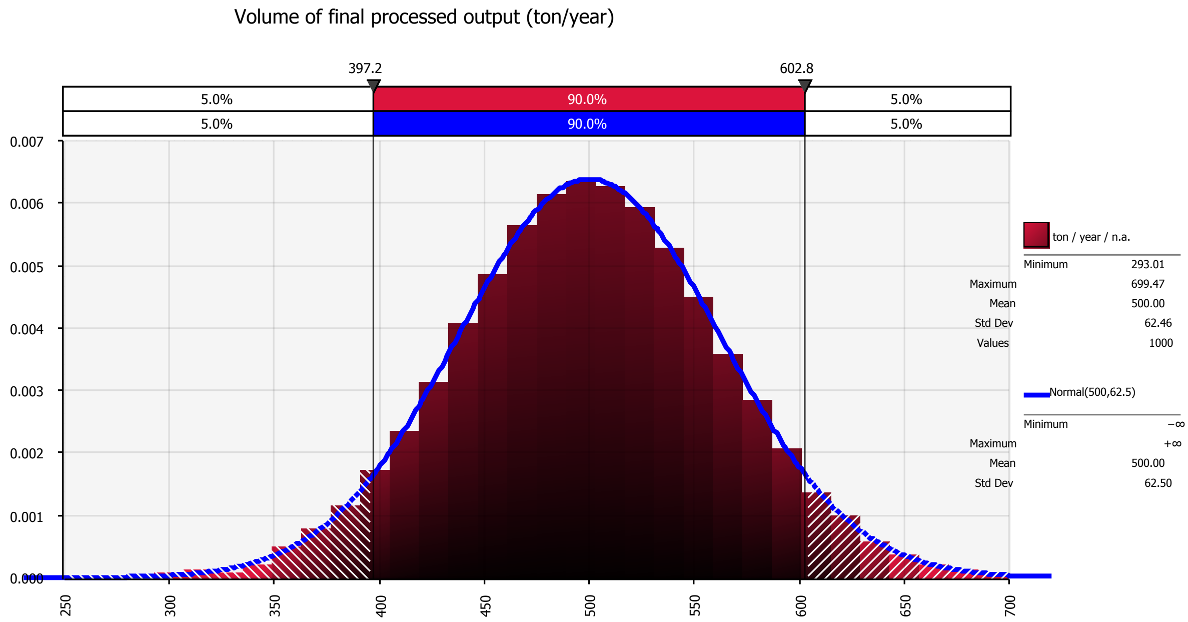
- Similarly, the total average revenue post processing of *Saccharina latissima* in Europe is estimated at €34,547,348 with 95% of the iterations falling within the values of €24,490,575 and €42,869,181.

Figure 1: probability distribution of profit post processing for the production of *Saccharina latissima* in Europe under the alternative scenario



Visually expressed, Figure 2 shows the probability distribution for operating profit post the processing for *Saccharina latissima* production in Europe under the alternative scenario. The value of the lower bound is set to zero to illustrate the probability of generating negative or zero net returns from the production chain across all segments. The upper CI bound of 2.5% reveals an associated profit value of €18.67 million. The mean, maximum and minimum values from the 1,000 iterations are displayed in the legend to the right hand side of the graph. These are €10.03 million, -€4.71 million and €21.60 million, respectively.

Figure 2: Probability distribution for operating profit



4. What is Seaweed's Contribution to People

The ecosystem services provided by the natural seaweed fields - the so-called kelp forests - off the coasts of France, Ireland, Scotland and England, among others, have been studied by various authors (Smale et al. 2013; Augyte et al. 2017). Smale et al. (2013) have focused on the seas around the United Kingdom and conclude that the naturally occurring seaweed fields play an important role in promoting and preserving biodiversity and contribute to the productivity of the ecosystem and the food web. In addition, the seaweed contributes to coastal protection and cultural services such as tourism.

Others, e.g. Steneck et al. (2002), point to the danger of overfishing of the seaweed fields and the subsequent loss of marine biodiversity. Large-scale seaweed cultivation - within the dikes or in the mouths of rivers - can reduce the leaching of prevent phosphate and nitrate from entering the sea (Hasselström et al. 2020; Jiang et al. 2020). In fish farming at sea, metabolic waste products excreted by fish leach nutrients to the surrounding ecosystem. By using seaweed around fish farming cultivation allows part of these nutrients to be absorbed (Abreu et al. 2009; Laramore et al. 2018). In a Swedish study, it was concluded that large-scale seaweed farming can sequester a significant share of annual anthropogenic nitrogen and phosphorus inflows to the basins of the Swedish west coast (8% of N and 60% of P)(Hasselström et al. 2020). Another study in Norway, highlights that >10% of waste nutrients from a salmon farm could be assimilated by adjacent seaweed farming, and at the same time higher seaweed yields were realized (Fossberg et al 2018). Furthermore, seaweed may serve as a CO_2 sink (Froehlich et al. 2019). Chung et al. (2013) developed the Coastal CO_2 Removal Belt, in which both natural and man-made seaweed species have been used for the removal of CO_2 from seawater

In fish farming, fish lice control is an expensive item for entrepreneurs (Liu and Bjelland 2014). Findings of entrepreneurs - including Hortimare - suggest that with seaweed cultivation around a fish farm, the amount of fish lice is reduced. In addition, there are opportunities to seaweed in fish food as an immune stimulant, and thus contribute to the prevention of diseases (Reverter et al. 2014; Vatsos and Rebours 2015). Marine algae are often considered as a biofertilizer, soil improver, and in general as a promoter of healthier plant-based products as algae stimulate the growth of many plants (Umanzor et al. 2020)..

An attempt has been made by to improve the ecosystem services of the natural common seaweed fields off the coast of northern Chile (Rebours et al. 2014). This focused on the value of the production service, the value of other types of plants and animals that grow through seaweed entering the ecosystem, the value for scientific research, the value as a climate buffer, and of cultural heritage. They conclude that 75% of the total value comes from the provisioning services, namely the use of seaweed for the production of thickeners.

5. Two avenues for capitalization of ecosystem services

Carbon and nutrient trading

Carbon offsetting is about receiving credit for reducing, avoiding, or sequestering carbon. Currently it is a part of the portfolio of solutions to mitigate carbon emissions, and thus climate change, both through markets and policy. Froehlich et al (2019), who made this observation, also add that efforts nowadays primarily address land-based re- or afforestation and preservation. But, on the other hand, many sectors are competing for land and available space becomes limiting, which is a boost for the interest in the rapidly growing aquatic farming sector of seaweed aquaculture (ibid).

This does however not mean that seaweed easily will become a part of the blue carbon strategy and policy. Krause-Jensen et al (2019) found that there is compelling evidence that macroalgal can contribute to bury carbon, if properly managed, but that this has not sufficed to integrate macroalgae into blue carbon initiatives. Their inclusion is even controversial, Krause-Jensen et al (2019) emphasize. The disagreement, they argue, may be narrowed down to find the donor sites of macroalgal carbon and the sink locations where macroalgal carbon accumulates and persists over relevant time scales. In their view it is not a question of whether or not macroalgal carbon is a blue carbon resource, but how to include macroalgae in carbon accounting and blue carbon schemes. For this to happen, Krause-Jensen et al (2019) made the following points:

- for macroalgae to play a role in climate change mitigation actions, biomass needs to be extensive and with a sufficiently high sequestration rate at a national scale.
- It must be 'actionable' as a blue carbon resource, that is, human action can drive a change in the amount of carbon being sequestered.
- Current frameworks and regulations need to be reconsidered in order to include macroalgal carbon in mitigation and adaptation actions, as well as in national blue carbon accounting.
- Currently, the Verified Carbon Standard (VCS) is the most commonly used verification standard and includes a number of requirements for any project: the GHG emissions reduction or removal must be 'real', 'measurable', 'permanent', 'unique' and 'additional'.

Whether these requirements are suited to dealing with macroalgae blue carbon remains to be assessed, Krause-Jensen et al (2019) conclude. They add that the Verified Carbon Standard VCS now specifically excludes allochthonous carbon stored within seagrass, saltmarsh and mangrove ecosystems from accounting. The challenge is to get to trustworthy impact assessments. Regarding such assessments, Van den Burg et al (2019) warns that a process of upscaling might lead to unknown environmental impacts (trade-offs) and benefits are not easily quantified, not only due to a lack of data but also the comparison between land-based and sea-based farming systems is inherently difficult. In addition, the requirements are demanding (Krause-Jensen et al 2019). For *real and measurable* impacts, emission reductions and removals generated must be proven to have genuinely taken place. *Permanent* means that the GHG emission reductions or avoidance generated by actions need be maintained over time scales of 10 –100 years. *Unique* means that credited carbon emission reductions must be unique and associated with a single GHG emission reduction or removal activity. Consequently, current schemes only credit autochthonous carbon, as there is a risk that allochthonous carbon may have been previously credited (double accounting). *Additional* says that GHG emission reductions and removals must be additional to what would have happened if the project had not been carried out. The procedures for demonstrating additionality are not, conceptually, different for macroalgae than for other blue carbon habitats, except for the challenge of demonstrating the additionality of carbon emission reduction/sequestration at a sink site when the action was undertaken at a different, donor site.

Some of the carbon credited in forests on land may eventually be exported to the ocean and this may be the reason for the current reluctance to credit allochthonous C in habitats. Incorporating macroalgal BC into accounting and mitigation strategies may therefore require a paradigm shift in the accounting procedures, and more precision in defining the risks of double counting than just considering all allochthonous C questionable. Further studies fingerprinting the C of BC habitats and documenting connectivity between habitats will support such developments. This paradigm shift should also be applied to BC sequestered beyond seagrass, mangrove and saltmarsh ecosystems (Krause-Jensen et al 2019).

Table 2: Science and management/policy agendas needed for including macroalgae in the blue carbon paradigm and schemes (Krause-Jensen et al. 2018).

The science agenda	1. Development of reliable tools to fingerprint the contribution of macroalgae to oceanic C sink sites beyond the habitats 2. Field evidence, derived with the tools above, of macroalgal burial rates and stocks in oceanic C sink sites beyond the habitats. 3. Improved estimates of the global area and production of macroalgae, resolved to the level of major functional groups. 4. Case studies providing evidence of effects of management practices, in terms of protection and enhancement of macroalgal area and production, for carbon sequestration beyond the habitat, to meet the additional requirement.
The management/policy agenda:	1. A certification system of the CO2 emissions avoided and/or of enhanced sequestration through protection, restoration of habitats and seaweed farming. 2. Revising crediting schemes to incorporate macroalgal carbon sequestered beyond these habitats. 3. Establishing fair mechanisms apportioning macroalgal carbon sequestered in shared deep sinks among the participating nations.

An important condition for increased support of marine markets is the awareness and willingness of policy leadership to invest. The new President of the European Commission Ursula von der Leyen aims in her Agenda 2019-2014 for A Sustainable Europe Investment Plan and a New Circular Economy Action Plan focusing on sustainable resource use propose. On the agenda is also the intentions to extend the Emissions Trading System to cover the maritime sector[4].

Lessons learned from shell fish aquaculture

The potential for nutrient and carbon trading does also receive increasing attention within the realm of shellfish culture, which is, like seaweed cultivation, another form of extractive aquaculture. The question is therefore if seaweed culture may learn from this? The concept of a nutrient credit trading program for shellfish is to establish a market-based approach to help control nutrient discharges by providing economic incentives for achieving continued nutrient load reductions to meet water quality goals. Ferreira and Bricker (2016) estimated that the removal of nitrogen through shellfish culture in Europe potentially equivalents to €507 million. Likewise van de Schatte Oliver et al (2018) estimated that globally cultivated bivalves remove 49,000 tonnes of nitrogen and 6,000 tonnes of phosphorus, worth a potential $1.20 billion, against a total market value of shellfish products (meat, pearls shells) of $29.1 billion. Ferreira and Bricker (2019) highlight that legal and management instruments are not sufficient yet to integrate nutrient trading into EU directives and thus into business models of individual farmers. It is interesting that the US seems more advanced with regard to nutrient credit trading frameworks, albeit speculating on why this is the case. Potential reasons are: (i) differences in legislation and policy instruments, (ii) concerns that reduced focus on source control may detract from efforts to reduce land-based nutrient discharge; and (iii) uncertainties about effectiveness as a management tool. They argue that if Europe is to move towards integrated nutrient management measures, which insofar as possible internalize the mechanisms used at the water basin scale.

Payments for ecosystem services

Smith et al (2013) see the basic idea behind Payment for Ecosystem Services (PES) as one where those who provide ecosystem services, like any service, should be paid for the service. By that we can put a price on previously un-priced ecosystem services like climate regulation, water quality regulation and the provision of habitat for wildlife. They then become part of the wider economy.

Table 3: Seven key principles, which should ideally underpin any PES scheme (DEFRA 2013)

Principle	Description
Voluntary:	stakeholders enter into PES agreements on a voluntary basis
Beneficiary pays	payments are made by the beneficiaries of ecosystem services (individuals, communities and businesses or governments acting on behalf of various parties)
Direct payment	payments are made directly to ecosystem service providers (in practice, often via an intermediary or broker)
Additionality	payments are made for actions over-and-above those which land or resource managers would generally be expected to undertake (note that precisely what constitutes additionality will vary from case-to-case but the actions paid for must at the very least go beyond regulatory compliance)
Conditionality	payments are dependent on the delivery of ecosystem service benefits. In practice, payments are more often based on the implementation of

[4] https://ec.europa.eu/commission/sites/beta-political/files/political-guidelines-next-commission_en.pdf

	management practices which the contracting parties agree are likely to give rise to these benefits
Ensuring permanence	management interventions paid for by beneficiaries should not be readily reversible, thus providing continued service provision
Avoiding leakage	PES schemes should be set up to avoid leakage, whereby securing an ecosystem service in one location leads to the loss or degradation of ecosystem services elsewhere

In addition, establishing the baseline position, i.e. the likely future provision of the relevant ecosystem services in the absence of the PES scheme, will be critical since this will allow for accurate monitoring which will, in turn, indicate the level of additionality being delivered, thus reassuring buyers that the requisite services are indeed being provided. In developing a PES scheme, it may also be appropriate to undertake stakeholder engagement with those likely to be affected by the scheme.

There are three broad types of PES scheme: (1) public payment schemes through which government pays land or resource managers to enhance ecosystem services on behalf of the wider public; (2) private payment schemes, self-organised private deals in which beneficiaries of ecosystem services contract directly with service providers; and (3) public-private payment schemes that draw on both government and private funds to pay land or other resource managers for the delivery of ecosystem services. For a PES scheme to work it must represent a win for both buyers and sellers. PES may be positive from a buyer's perspective if the payments are less than those associated with any alternative means of securing the desired service. For example, it may be less expensive for a water utility to pay land owners for improved catchment management than to pay for additional water treatment. PES schemes may be positive from a seller's perspective if the level of payment received at least covers the value of any returns foregone as a result of implementing the agreed interventions. For example, a farmer may be willing to create ponds for enhanced water storage if the payments received at least cover the costs of doing so, including the costs associated with any lost agricultural production.

Four principal groups are typically involved in a PES scheme:

- 'buyers': beneficiaries of ecosystem services who are willing to pay for them to be safeguarded, enhanced or restored;
- 'sellers': land and resource managers whose actions can potentially secure supply of the beneficial service;
- 'intermediaries': who can serve as agents linking buyers and sellers and can help with scheme design and implementation; and
- 'knowledge providers': these include resource management experts, valuation specialists, land use planners, regulators and business and legal advisors who can provide knowledge essential to scheme development.

It is important to note that some organisations could conceivably play different roles in different PES schemes. For example, a wildlife charity might: sell ecosystem services in its role as a land owner or custodian; take on the role of intermediary to facilitate delivery of a PES scheme; buy ecosystem services on behalf of its membership; or provide knowledge and advice on appropriate management practices.
The way that buyers and sellers can be configured in scheme development can also vary. For example:

- ‘one-to-one’: for example, where a company enters into a contract with a single major land-owner to provide enhanced carbon sequestration;
- ‘one-to-many’: for example, where a water utility makes arrangements via a broker to pay many farm businesses for water-sensitive management practices in a key catchment;
- ‘many-to-one’: for example, where multiple buyers together invest in the development and maintenance of urban green space; and
- ‘many-to-many’: for example, where government pays farmers for sympathetic land management practices on behalf of the wider public.

Ecosystem services can be packaged in three distinct ways:

- Bundling: a single buyer, or consortium of buyers, pays for the full package of ecosystem services that arise from the same parcel of land or body of water. For example, an agri-environment scheme funded by government on behalf of the wider public. In this case, payments are made for the full suite of ecosystem services provided, as all will benefit some proportion of the population (eg landscape benefits may be felt by local people and water quality benefits by people across the relevant catchment).
- Layering: multiple buyers pay separately for the ecosystem services that arise from the same parcel of land or body of water; layering is also sometimes referred to as ‘stacking’. For example, an area of peatlan communities, and the biodiversity benefits by a wildlife charity on behalf of its membership.
- Piggy-backing: in this case, not all of the ecosystem services generated from a single parcel of land or body of water are sold to buyers. Instead, a single service (or possibly several services), is sold as an umbrella service, whilst the benefits provided by other services accrue to users free of charge (ie the beneficiaries ‘free ride’). For example, a business pays an upstream land manager for riparian restoration work to reduce the downstream flood risk to its bankside facilities. These improvements simultaneously improve water quality, enhance recreational values and provide habitat for wildlife. However, no buyers are found for these additional services and the benefits they provide are received at no cost to end users.

In seeking to establish a PES scheme, it is also critical to explore possible unintended consequences. Factors to consider include the risk that increasing the provision of an ecosystem service in one area will lead to pressure on ecosystem services elsewhere (leakage)? For example, payments for enhanced service provision on one parcel of land might provide the income needed to begin harmful activities on another or an adjacent land use may be intensified to compensate for reduced output in the area covered by the PES scheme. Furthermore, there might be a risk the PES scheme is perceived as unfair. For example, to maximise the provision of additional ecosystem services, the funds available through a PES scheme would be best directed to those whose land or resources had the greatest potential to deliver additional services and away from those whose land or resources already provided the required services. This could lead to payments being made to land or resource managers who had not previously managed their land or resources in an environmentally-sensitive manner and so prompt accusations of unfairness. Lastly, there is the risk of creating perverse incentives. For example, land or resource managers paid to sequester carbon might plant non-native tree species which sequester carbon at a faster rate than indigenous species, yet broad swathes of non-native vegetation might lead to detrimental impacts on biodiversity and contribute to wider problems such as acidification, disease transmission or fire risk.

6. Discussion

Economic performance

Comparing the results from the simple model between the current means of production with the alternative scenario selected, it can be observed that production of farmed *Saccharina latissima* for alginic acid is not financially viable in Europe at this time. However, if the means of production and/or scale of individual seaweed farms advances in the future, production may become profitable assuming that a minimum breakeven price can be achieved at the processing segment. If the means of production and/or scale of individual seaweed hatchery and farms advances in the future, production of food is expected to be profitable in the future. In addition, the production of alternative high-end products may also become profitable assuming that a minimum breakeven price of €70.17/kg can be achieved at the processing segment.

Ecosystem services

Seaweeds provide various ecosystem services. Despite the vast literature on values of ecosystem services, there exists no commercial value for the majority of regulating and cultural ecosystem services on the market to date. Moreover, the market values that do exist for regulating and cultural services are indirectly paid through travel-related costs for recreation or hedonic premiums included in the sale of properties along pristine coastlines (Lopes and Videira 2013). Without generating market values for existing ecosystem services, the risk of the degradation of these services through the lack of internalising negative externalities or costs to its destruction arises. Emerging markets that place economic values to ecosystem services have begun to arise, as seen through the carbon and nutrient trading markets. Furthermore, within the large body of literature that looks at mechanisms to generate payment for ecosystem services and natural capital (Gómez-Baggethun et al. 2010; Binet et al. 2013), the bulk of it was developed with terrestrial ecosystems in mind. Greater effort is needed to develop methods dedicated to the marine realm (Hooper et al. 2019).

Towards quantification and monetarisation

Of the ecosystem services provided by seaweed cultivation, some are considerable more studied than others. There is a higher degree of certainty for ecosystem services that are provided on a local scale (e.g. reduction of fish lice) whereas a global topic such as CO2 sequestration faces greater uncertainty. In between sits N and P remediation, a well-known effects of seaweed cultivation but the effect on a regional scale, on nutrients flows and food webs requires further analysis (van der Meer 2020). The knowledge base required for quantification and monetarisation of these needs to be expanded before credits can be provided and traded.

Of a different type are those services that are of direct benefit to a beneficiary and can be created by seaweed farming. This includes e.g. sea lice control; it is directly clear who benefits, who can lower spending on sea lice control and has an interest in seaweed cultivation. Payment for such services can be developed if there is sufficient certainty about benefits

Does can this close the financial gap?

In this paper we have provided an economic assessment of *Saccharina latissima* cultivation for production of a product comparable to alginic acid. The economic feasibility was low and in the absence of certainty about quantity and value of ecosystem services provided, nutrient and/or carbon trading nor payment for ecosystem services are currently not likely to close the financial gap. Profitable seaweed cultivation requires targeting higher value markets that can pay higher prices for raw material. The valuation and monetarisation of ecosystem services might then provide additional sources of income.

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References

Abreu, M.H., D.A. Varela, L. Henríquez, A. Villarroel, C. Yarish, I. Sousa-Pinto, and A.H. Buschmann. 2009. "Traditional vs. Integrated Multi-Trophic Aquaculture of Gracilaria Chilensis C. J. Bird, J. McLachlan & E. C. Oliveira: Productivity and Physiological Performance." Aquaculture 293 (3–4): 211–20. https://doi.org/10.1016/j.aquaculture.2009.03.043.

Augyte, Simona, Charles Yarish, Sarah Redmond, and Jang K. Kim. 2017. "Cultivation of a Morphologically Distinct Strain of the Sugar Kelp, Saccharina Latissima Forma Angustissima, from Coastal Maine, USA, with Implications for Ecosystem Services." Journal of Applied Phycology 29 (4): 1967–76. https://doi.org/10.1007/s10811-017-1102-x.

Austen M.C., Anderson P., Armstrong C., Döring R., Hynes S., Levrel H., Oinonen S., Ressurreição A. (2019) Valuing Marine Ecosystems - Taking into account the value of ecosystem benefits in the Blue Economy, Coopman, J., Heymans, JJ., Kellett, P., Muñiz Piniella, A., French, V., Alexander, B. [Eds.] Future Science Brief 5 of the European Marine Board, Ostend, Belgium. 32pp. ISBN: 9789492043696 ISSN: 4920-43696 DOI: 10.5281/zenodo.2602732

Baker, R. and Ruting, B. (2014), Environmental Policy Analysis: A Guide to Non-Market Valuation, Productivity Commission Staff Working Paper, Canberra

Banach, J L, E. F. Hoek-van den Hil, and H. J. der Fels-Klerx. 2020. "Food Safety Hazards in the European Seaweed Chain." Comprehensive Reviews in Food Science and Food Safety, January, 1541-4337.12523. https://doi.org/10.1111/1541-4337.12523.

Barbier E.B., Hacker S.D., Kennedy C., Koch E.W., Stier A.C., and Silliman, B.R. (2011) The value of estuarine and coastal ecosystem services. Ecological Monographs 81 (2), 169–193.

Beaumont N.J., Austen M.C., Mangi S.C. and Townsend M.T. (2008), Economic valuation for the conservation of marine biodiversity, Marine Pollution Bulletin, 56 (3), pp. 386-396.

Binet, Thomas, Pierre Failler, Pablo N Chavance, and Mohamed Abidine Mayif. 2013. "First International Payment for Marine Ecosystem Services: The Case of the Banc d'Arguin National Park, Mauritania." Global Environmental Change 23 (6): 1434–43. https://doi.org/https://doi.org/10.1016/j.gloenvcha.2013.09.015.

Blackwell B.D. (2006), The economic value of Australia's natural coastal assets: some preliminary findings, Australian and New Zealand Society for Ecological Economics Conference Proceedings: Ecological Economics in Action. December 11–13, 2005, New Zealand.

Brenner-Guillermo, J. (2007). Valuation of ecosystem services in the catalan coastal zone, Ph.D. Thesis, Polytechnic University of Catalonia, Barcelona, 186 pp.

Burg, S.W.K. van den, A.P. van Duijn, H. Bartelings, M.M. van Krimpen, and M. Poelman. 2016. "The Economic Feasibility of Seaweed Production in the North Sea." Aquaculture Economics and Management 20 (3). https://doi.org/10.1080/13657305.2016.1177859.

Cabral, P., H. Levrel, F. Viard, K. Frangoudes, S. Girard, and P. Scemama. 2016. "Ecosystem Services Assessment and Compensation Costs for Installing Seaweed Farms." Marine Policy 71: 157–65. https://doi.org/10.1016/j.marpol.2016.05.031.

Cage P. (2018), *Kelp and carbon sequestration: exporting terrestrial GHG accounting to the deep sea*, GHG Management Institute, date viewed 11 September 2019, available at:
Chung I.K., Oak J.H., Lee J.A., Shin J.A., Kim J.G., Park K.S. (2013), Installing kelp forests/seaweed beds for mitigation and adaptation against global warming: Korean Project Overview, ICES Journal of Marine Science, 70 (5), pp. 1038-1044.

Chung, Ik Kyo, Jung Hyun Oak, Jin Ae Lee, Jong Ahm Shin, Jong Gyu Kim, and Kwang-Seok Park. 2013. "Installing Kelp Forests/Seaweed Beds for Mitigation and Adaptation against Global Warming: Korean Project Overview." ICES Journal of Marine Science 70 (5): 1038–44. https://doi.org/10.1093/icesjms/fss206.

Costanza R., d'Arge R., de Groot R.S., Farber S., Grasso M., Hannon B., Limburg K., Naeem S., O'Neill R.V., Paruelo J., Raskin R.G., Sutton P. and van den Belt M. (1997), The value of the world's ecosystem services and natural capital, *Nature*, 387 (1997), pp. 253-260.

Costanza R., de Groot R., Braat L., Kubiszewski I., Fioramonti L., Sutton P., Farber S. and Grasso M. (2017), Twenty years of ecosystem services: how far have we come and how far do we still need to go?, *Ecosystem Services*, 28, pp. 1-16.

Costanza R., de Groot R., Sutton P., van der Ploeg S., Anderson S.J., Kubiszewski I., Farber S., Turner R.K. (2014), Changes in the global value of ecosystem services, *Global Environmental Change*, 26, pp. 152–158

Costello, C., L. Cao, S. Gelcich et al. 2019. The Future of Food from the Sea. Washington, DC: World Resources Institute. Available online at www.oceanpanel.org/future-food-sea
Daily G.C. (1997), "Nature's Services: Societal Dependence on Natural Ecosystems", Island Press, Washington D.C.

DEFRA. 2013. "Payments for Ecosystem Services: A Best Practice Guide." Department for Environment Food and Rural Affairs (DEFRA), no. May: 85p. https://ecosystemsknowledge.net/sites/default/files/wp-content/uploads/pb13932a-pes-bestpractice-annexa-20130522.pdf.

Elizondo-González, R., E. Quiroz-Guzmán, C. Escobedo-Fregoso, P. Magallón-Servín, and A. Peña-Rodríguez. 2018. "Use of Seaweed Ulva Lactuca for Water Bioremediation and as Feed Additive for White Shrimp Litopenaeus Vannamei." PeerJ 2018 (3). https://doi.org/10.7717/peerj.4459.

Froehlich, Halley E, Jamie C Afflerbach, Melanie Frazier, and Benjamin S Halpern. 2019. "Blue Growth Potential to Mitigate Climate Change through Seaweed Offsetting." Current Biology : CB 29 (18): 3087-3093.e3. https://doi.org/10.1016/j.cub.2019.07.041.

Gereffi, Gary, and Karina Fernandez-Stark. 2016. "Global Value Chains Analysis: A Primer." Durham.

Gómez-Baggethun, Erik, Rudolf de Groot, Pedro L. Lomas, and Carlos Montes. 2010. "The History of Ecosystem Services in Economic Theory and Practice: From Early Notions to Markets and Payment Schemes." Ecological Economics 69 (6): 1209–18. https://doi.org/10.1016/j.ecolecon.2009.11.007.

Hasselström, Linus, Jean-Baptiste Thomas, Jonas Nordström, Gunnar Cervin, Göran M Nylund, Henrik Pavia, and Fredrik Gröndahl. 2020. "Socioeconomic Prospects of a Seaweed Bioeconomy in Sweden." Scientific Reports 10 (1): 1610. https://doi.org/10.1038/s41598-020-58389-6.

Hooper, Tara, Tobias Börger, Olivia Langmead, Oceane Marcone, Siân E Rees, Olivia Rendon, Nicola Beaumont, Martin J Attrill, and Melanie Austen. 2019. "Applying the Natural Capital Approach to Decision Making for the Marine Environment." Ecosystem Services 38: 100947. https://doi.org/https://doi.org/10.1016/j.ecoser.2019.100947.

https://ghginstitute.org/2018/09/06/kelp-and-carbon-sequestration-exporting-terrestrial-ghg-accounting-to-the-deep-sea/

Jansen, H.M., S. Van Den Burg, B. Bolman, R.G. Jak, P. Kamermans, M. Poelman, and M. Stuiver. 2016. "The Feasibility of Offshore Aquaculture and Its Potential for Multi-Use in the North Sea." Aquaculture International 24 (3). https://doi.org/10.1007/s10499-016-9987-y.

Jiang, Zhibing, Jingjing Liu, Shanglu Li, Yue Chen, Ping Du, Yuanli Zhu, Yibo Liao, et al. 2020. "Kelp Cultivation Effectively Improves Water Quality and Regulates Phytoplankton Community in a Turbid, Highly Eutrophic Bay." Science of the Total Environment 707 (March): 135561. https://doi.org/10.1016/j.scitotenv.2019.135561.

Krause-Jensen, Dorte, Paul Lavery, Oscar Serrano, Núria Marbà, Pere Masque, and Carlos M. Duarte. 2018. "Sequestration of Macroalgal Carbon: The Elephant in the Blue Carbon Room." Biology Letters 14 (6): 20180236. https://doi.org/10.1098/rsbl.2018.0236.

Kroon, F.J., B. Schaffelke, and R. Bartley. 2014. "Informing Policy to Protect Coastal Coral Reefs: Insight from a Global Review of Reducing Agricultural Pollution to Coastal Ecosystems." Marine Pollution Bulletin 85 (1): 33–41. https://doi.org/10.1016/j.marpolbul.2014.06.003.

Laramore, S., R. Baptiste, P.S. Wills, and M.D. Hanisak. 2018. "Utilization of IMTA-Produced Ulva Lactuca to Supplement or Partially Replace Pelleted Diets in Shrimp (Litopenaeus Vannamei) Reared in a Clear Water Production System." Journal of Applied Phycology, 1–8. https://doi.org/10.1007/s10811-018-1485-3.

Liu, Yajie, and Hans vanhauwaer Bjelland. 2014. "Estimating Costs of Sea Lice Control Strategy in Norway." Preventive Veterinary Medicine 117 (3–4): 469–77. https://doi.org/10.1016/j.prevetmed.2014.08.018.

Lopes, Rita, and Nuno Videira. 2013. "Valuing Marine and Coastal Ecosystem Services: An Integrated Participatory Framework." Ocean and Coastal Management 84 (November): 153–62. https://doi.org/10.1016/j.ocecoaman.2013.08.001.

Meer, Jaap van der. 2020. "Limits to Food Production from the Sea." Nature Food 1 (12): 762–64. https://doi.org/10.1038/s43016-020-00202-8.

Rebours, Céline, Eliane Marinho-Soriano, José A. Zertuche-González, Leila Hayashi, Julio A. Vásquez, Paul Kradolfer, Gonzalo Soriano, et al. 2014. "Seaweeds: An Opportunity for Wealth and Sustainable Livelihood for Coastal Communities." Journal of Applied Phycology 26 (5): 1939–51. https://doi.org/10.1007/s10811-014-0304-8.

Reverter, M., N. Bontemps, D. Lecchini, B. Banaigs, and P. Sasal. 2014. "Use of Plant Extracts in Fish Aquaculture as an Alternative to Chemotherapy: Current Status and Future Perspectives." Aquaculture 433 (September): 50–61. https://doi.org/10.1016/j.aquaculture.2014.05.048.

Selnes, Trond, Else Giesbers, and Sander W. K. van den Burg. 2021. "Innovation and Collaboration: Opportunities for the European Seaweed Sector in Global Value Chains." Journal of Marine Science and Engineering 9 (7): 693. https://doi.org/10.3390/jmse9070693.

Smale, Dan A., Michael T. Burrows, Pippa Moore, Nessa O'Connor, and Stephen J. Hawkins. 2013. "Threats and Knowledge Gaps for Ecosystem Services Provided by Kelp Forests: A Northeast Atlantic Perspective." Ecology and Evolution 3 (11): 4016–38. https://doi.org/10.1002/ece3.774.

STENECK, R., GRAHAM, M., BOURQUE, B., CORBETT, D., ERLANDSON, J., ESTES, J., & TEGNER, M. (2002). Kelp forest ecosystems: Biodiversity, stability, resilience and future. Environmental Conservation, 29(4), 436-459. Retrieved June 27, 2021, from http://www.jstor.org/stable/44520631

Stévant, Pierrick, Céline Rebours, and Annelise Chapman. 2017. "Seaweed Aquaculture in Norway: Recent Industrial Developments and Future Perspectives." Aquaculture International 25 (4): 1373–90. https://doi.org/10.1007/s10499-017-0120-7.

Umanzor, Schery, Sookkyung Shin, Charles Yarish, Simona Augyte, and Jang K. Kim. 2020. "Exploratory Evaluation of the Effects of Kelpak® Seaweed Extract on Cultivated Kelp Saccharina Spp. Exposed to Sublethal and Lethal Temperatures." Journal of the World Aquaculture Society, no. November 2019: 1–10. https://doi.org/10.1111/jwas.12687.

Vatsos, Ioannis N, and Celine Rebours. 2015. "Seaweed Extracts as Antimicrobial Agents in Aquaculture." Journal of Applied Phycology 27 (5): 2017–35. https://doi.org/10.1007/s10811-014-0506-0.