State of knowledge regarding the potential of macroalgae cultivation in providing climate-related and other ecosystem services

An Eklipse Expert Working Group report

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State of knowledge regarding the potential of macroalgae cultivation in providing climate-related and other ecosystem services

May 2022

A report of the Eklipse Expert Working Group on Macroalgae cultivation and Ecosystem Services

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Glossary

TERM	DEFINITION	KEY REFERENCES
Ecosystem services	In CICES ecosystem services are defined as the contributions that ecosystems make to human well-being, and are distinct from the goods and benefits that people subsequently derive from them	www.cices.eu; Haines-Young & Potschin (2018)
Land-based cultivation	Cultivation of macroalgae on land	
Transitional waters	Estuarine or brackish waters	Basset et al. (2013)
Near-shore, sheltered	Marine waters <50 m water depth & <3 nautical miles distance to shore	Bak et al. (2020)
Near-shore, exposed	Marine waters >50 m depth & <3 nautical miles from shore	Bak et al. (2020)
Offshore	>3 nautical miles from shore	Bak et al. (2020)
Green Deal	Growth strategy of the EU to promote ambitious environment, climate and energy policies, with the ultimate objective to boost sustainable development	https://wecoop.eu/glossary/green-deal/
European Blue Bioeconomy	Any economic activity associated with the use of renewable aquatic biological resources to make products	https://www.eumofa.eu/documents/20178/84590/Blue+bioeconomy_Final.pdf
Blue-Growth	Sustainable growth of the marine and maritime sectors	https://s3platform.jrc.ec.europa.eu/blue-growth
Trade-offs	A situation in which you balance two opposing situations or qualities	https://dictionary.cambridge.org/pt/dicionario/ingles/trade-off
Blue Carbon	The carbon stored in coastal and marine ecosystems	https://www.iucn.org/resources/issues-briefs/blue-carboN
EMFF	European Maritime and Fisheries Fund	https://ec.europa.eu/oceans-and-fisheries/funding/european-maritime-and-fisheries-fund-emff_en

1 Summary

Macroalgae (or seaweed) aquaculture can potentially provide many ecosystem services, including climate change mitigation, coastal protection, preservation of biodiversity and improvement of water quality. Nevertheless, there are still many constraints and knowledge gaps that need to be overcome, as well as potential negative impacts or scale-dependent effects that need to be considered, before macroalgae cultivation in Europe can be scaled up successfully and sustainably. To investigate these uncertainties, the Expert Working Group (EWG) on Macroalgae was established. Its role was to determine the state of knowledge regarding the potential of macroalgae culture in providing climate-related and other ecosystem services (ES) and to identify specific knowledge gaps that must be addressed before harvesting this potential. The methodological framework combined a multiple expert consultation with Delphi process and a Quick Scoping Review (QSR). To analyse the outcome of both approaches, the EWG classified the findings under the categories Political, Environmental, Social, Technical, Economic and Legal (PESTEL approach) and categorised the ES based on the CICES 5.1 classification.

Although representative stakeholders from many different disciplines were contacted, the majority of responses to the Delphi process were from representatives of academia or research. While the results of each method differed in many ways, both methods identified the following top six ecosystem services provided by seaweed cultivation: i) provisioning food, ii) provisioning hydrocolloids and feed, iii) regulating water quality, iv) provisioning habitats, v) provisioning of nurseries and vi) regulating climate. Diverse technological knowledge gaps were identified by both methods at all scales of the macroalgae cultivation process, followed by economic and environmental knowledge gaps depending on the method used. Based on suggestions from the expert respondents in the Delphi process, there is a clear need for an European-wide strategy for reducing risks for seaweed producers, providing clear standards and guidelines for obtaining permits, and providing financial support to improve technological innovation, that will ensure consistent quality. Legal (e.g., safety regulations), economic (e.g., lack of demand for seaweeds in many countries) and technological (e.g., production at large scale) constraints represented almost 70% of the total responses in the Delphi process, whereas environmental and technical constraints were more dominant in the literature. The most commonly identified potential negative impacts of macroalgae cultivation both among the expert responses and the reviewed articles were unknown environmental impacts, e.g. to deep sea, benthic and pelagic ecosystems.

The present study provides an assessment of the state of knowledge regarding ES provided by seaweed cultivation and identifies the associated knowledge gaps, constraints and potential negative impacts. One of the main hurdles recognised by the EWG was the understanding of ES themselves by the different stakeholders, as well as the issue of scale. Studies providing clear evidence of ES provided by seaweed cultivation and/or valorisation of these services were lacking in the literature, and some aspects, like cultural impact etc. were missing in the responses to the questionnaires during the Delphi process. The issue of scale and scaling-up was omnipresent both in assessing the ES provided by seaweed cultivation and in identifying knowledge gaps, constraints and potential negative impacts. For example, the ES provided will depend on the scale of cultivation, the main technological knowledge gaps were often related to scale of cultivation. Likewise at a large scale of operations, there could be multiple associated potential side effects, which need to be further investigated. Based on the outcomes of this investigation, we provide an outlook with open questions that need to be answered to support the sustainable scaling-up of seaweed cultivation in Europe.

What is the state of knowledge regarding the potential of macroalgae culture in providing climate-related and other ecosystem services?

2 Background and objectives

There is growing awareness of and interest in the potential of macroalgae present in coastal ecosystems, including cultivation, to provide a wide range of solutions and mitigations to anthropogenically-induced problems (Xiao et al., 2017; Krause-Jensen et al., 2018; Duarte et al. 2021; Hughes, 2021). There is evidence that macroalgae aquaculture can potentially mitigate climate change (e.g. via uptake of carbon dioxide), protect coastlines, reduce local biodiversity loss and improve water quality, among other ecosystem services (Alleway et al., 2019; Duarte 2021). Nevertheless, there are still many constraints and knowledge gaps that need to be overcome, as well as potential negative impacts or scale-dependent effects (e.g. farm size or type of aquaculture) that need to be considered before macroalgae cultivation in Europe can up-scale successfully and sustainably.

This Eklipse request for knowledge synthesis (CfR.5/2020/1) aims to explore and map existing knowledge and identify knowledge gaps and trade-offs, to inform the future development of macroalgae culture strategies and policies. Furthermore, more knowledge is needed to evaluate impacts in terms of water, energy, land and sea use, changes in sedimentation rates and structure of local ecological communities, potential pollution and risk of releasing invasive alien species into the environment. This additional knowledge can contribute to the development, promotion and implementation of adequate and timely policy frameworks.

The requester, DG Maritime Affairs & Fisheries, Unit for Maritime Innovation, Marine Knowledge (DG MARE), is contemplating the development of an EU Algae Strategy. This strategy will take into consideration the multiple areas where macroalgae cultivation can contribute to the Green Deal, as well as, the importance of the overall algae sector for the development of a sustainable European Blue-bioeconomy. The successful development of this strategy requires that the knowledge gaps, constraints, and potential negative impacts related to macroalgae cultivation are identified to advise, through DG MARE, the development of relevant research activities under the next EMFF and Horizon Europe programmes. Therefore, the requester posed the following questions:

- **What is the state of knowledge regarding the potential of macroalgae culture in providing climate-related and other ecosystem services?**
- **Are there specific knowledge gaps to be addressed before harvesting this potential?**

To answer these questions, the Expert Working Group (EWG) on Macroalgae was established with the following objectives:

1. **To determine the state of knowledge regarding the potential of macroalgae culture in providing climate-related and other ecosystem services.**
2. **To identify specific knowledge gaps that must be addressed before harvesting this potential.**

The EWG has been meeting remotely weekly since February 22nd, 2021. The EWG received an introduction to the Eklipse call, a presentation on the requests and needs of the requester and the accompanying Document of Work, and a summary of the available methods by the Methods Expert Group (MEG). The EWG then selected four co-chairs to lead the subsequent meetings. After several discussions with the MEG, the EWG agreed on the methods to be used and was organised into two groups, with each group focusing on one of the two chosen methods. The details on the choice of methodology and expected outcomes are described below.

Delphi process covered views of not only scientists, but also other societal actors...

QSR provided a robust view on published literature...

3 Methodological framework

To achieve the objectives formulated above, a combination of the following two methods was followed: A Multiple Expert Consultation with Delphi Process and a Quick Scoping Review (QSR). These methods were conducted in parallel, rather than sequentially. A first round of questions was sent to selected experts as part of the Delphi Process, and then the EWG proceeded with the QSR. The use of the two methods helped to provide a more comprehensive answer to the request than the use of a single method, as shown in Table 1.

Table 1 Relationships between the request objectives and proposed knowledge synthesis methods.

QUESTIONS	QUICK SCOPING REVIEW	DELPHI PROCESS
What is the state of knowledge?	■ Provides synthesis of relevant literature ■ Generates knowledge base to hold against results from Delphi	■ Identifies and prioritises ecosystem services considered relevant ■ Identifies constraints for up-scaling ■ Identifies trade-offs and negative impacts
Are there specific knowledge gaps?	■ Evident if no literature is found in targeted areas of interests	■ Collects expert opinions on knowledge gaps ■ Formulates pathways to fill these gaps

The QSR focused on peer-reviewed literature, and the Delphi process captured the most recent and up-to-date views of experts from key sectors, including science, business and NGOs. Therefore, whilst the QSR provided a robust view on published literature and evidence, the Delphi Process covered views of not only scientists, but also other societal actors with practical and experience-based knowledge on the key issues in macroalgae cultivation.

To analyse the outcome of both approaches, we adopted the PESTEL approach (Basu 2004), classifying the findings according to external key factors, under the categories Political, Environmental, Social, Technical, Economic and Legal.

Ecosystem services (ES) were categorised based on the CICES 5.1 classification (Haines-Young and Potschin-Young 2018). Following these authors, who state that "CICES hierarchical structure is designed to allow users to go to the most appropriate level of detail required by their application and also to be able to group or combine results when making comparisons or more generalised reports", section 4.3 provides an overview of relevant ecosystem services at both section level and class level.

***Seaweed farm** near Oban, west coast of Scotland*

DELPHI

4 Delphi

4.1. Methodology

The Delphi process is an iterative technique for collecting information using expert consultation in a structured manner to produce forecasts and evaluate complex problems. This method was originally described by Dalkey and Helmer (1963) and has since been adapted to the fields of ecology, biology (Mukherjee et al. 2015) and many others. Because of the iterative and controlled nature of the process, which remains anonymous, it is a rigorous approach to eliciting expert knowledge. The main benefits of using the Delphi Process are that it is relatively rapid and low cost, rigorous, repeatable and transparent. The drawbacks of the method are that it can be time consuming for the experts and there can be some bias from experts with strong opinions or with conflicts of interest, if this is not managed carefully.

4.1.1 Adapting the Delphi method for this assignment

The Delphi process was adapted to address the questions raised by the EWG on macroalgae cultivation. We identified at least 130 experts from 40 countries, 15 of which were EU countries, to participate in three rounds of questioning. The geographic distribution of experts was global, but considering that the requester is interested in knowledge gaps surrounding macroalgae cultivation in Europe, the EWG agreed on including approximately 70% of the experts from Europe and 30% of the experts from elsewhere throughout the world. The experts invited were a mix of representatives from academia, industry, and organisations with particular interest in the marine environment, such as private environmental organisations or other stakeholders (tourism, fisheries, etc.). It was decided to aim for an approximate ratio of 3:3:2:2 representation from academia, industry, NGOs, and other marine organisations, respectively.

The work document prepared for the Delphi Process is presented in Annex 1. In addition to a general introduction and the actual questions for round 1, it also includes a set of background questions. These sections were created to facilitate the interpretation of the results and, if needed, to allow the implementation of selection criteria, which could be considered necessary to comply with the agreed balance between regions and between activity sectors.

The first round of the Delphi process adopted open questions, very much aligned with the questions provided by the Document of Work for the Macroalgae culture request (February 2021).

The first round of questions used to assess expert opinions was sent out to 104 experts from academia, industry, NGOs and other marine organisations. We received responses from 22 participants. Their responses were analysed and consolidated into a revised questionnaire for the second round of expert opinions.

For the second round of the Delphi process, we provided a list of Ecosystem Services, knowledge gaps, and negative impacts or trade-offs identified in the first round and asked the respondents to rank them in order of importance or severity (see Annex 1 for specific questions used in the second round). We received responses from six experts in the second round. The results obtained from the Delphi process are presented below.

Even though the initial methodology planned for three rounds in the Delphi process, after the first round, the EWG experts decided, based on the low response (6% after 2 rounds), that two rounds were enough. This decision was also validated by the Eklipse methods experts, considering the results from the first round, the planned questions for the second round and the time frame available.

4.2 Results

4.2.1 Characterization of respondents

The majority of responses to the first questionnaire were from representatives of academia or research (Fig. 1). Only four respondents were representatives from industry, and only single responses were obtained from NGOs, professional associations or international organisations. Among experts from academia and industry, the most dominant focus areas fell into the categories of macroalgae cultivation, macroalgae hatchery/nursery, and macroalgae processing (38%, 28%, and 18%, respectively; Fig. 2). Combined, these focus areas accounted for 84% of the responses. Only 5% of experts focused on marketing and sales, while focus areas such as macroalgae genetic characterization and breeding, education, management and conservation of brown algae, kelp forest studies, seaweed diversity/phylogeography, macroalgae diversity, macroalgae genetics, macroalgae horticulture, were represented by only 2.5% of participants. Over 40% of experts in the first round of the Delphi process were from Europe, but a global representation was present among the participants (Fig. 3). Nearly half of the experts had expertise in near-shore seaweed cultivation (either sheltered or exposed), while 21% had expertise in land-based cultivation and 15% had experience in offshore cultivation (Fig. 4). Very few experts had experience in cultivation in ponds or in transitional waters.

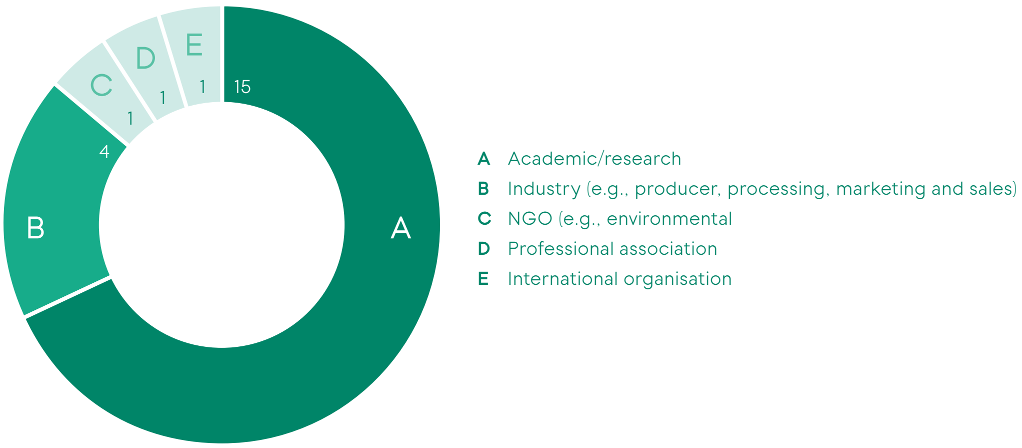


Fig. 1 *Distribution of experts in the different sectors related to seaweed cultivation that responded to the first round of the Delphi questionnaire*

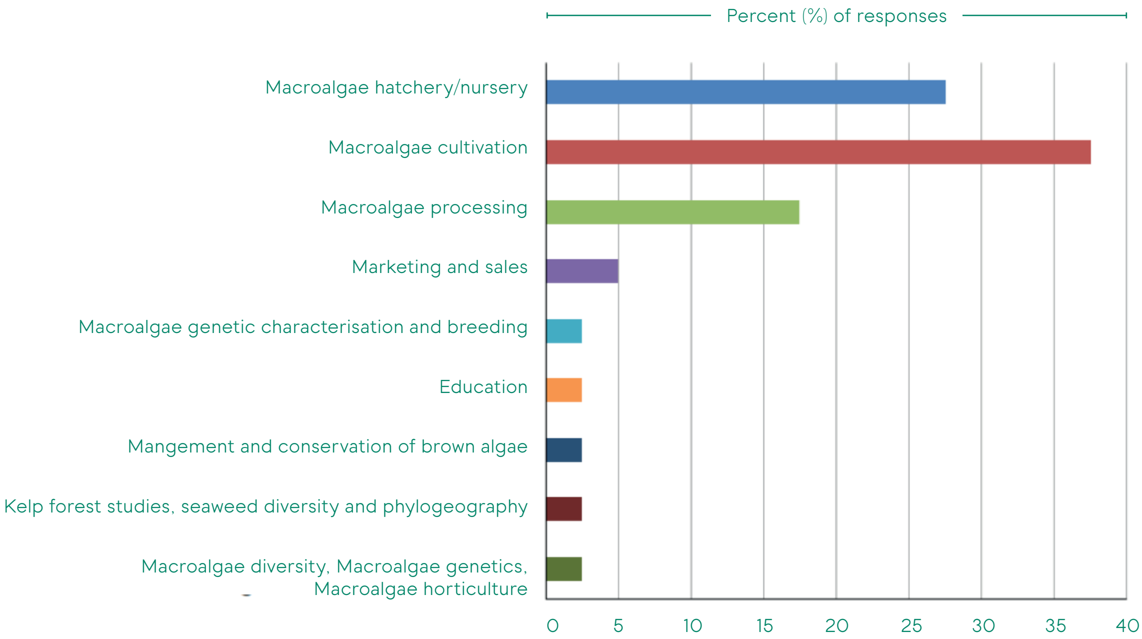


Fig. 2 *Focus areas of respondents from academia and industry to the Delphi questionnaire.*

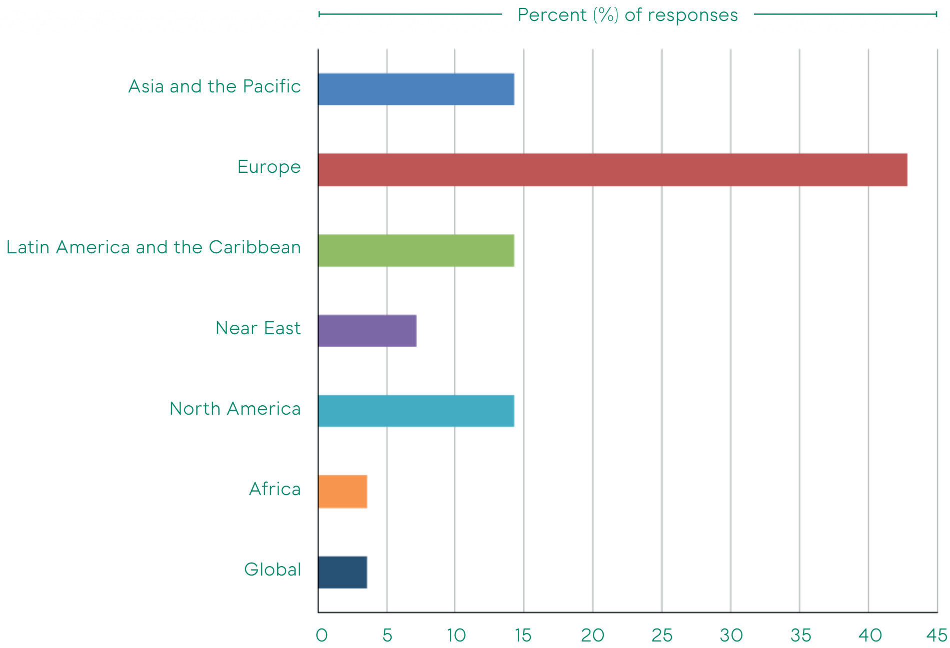


Fig. 3 Regional distribution of experts that participated in the Delphi questionnaire

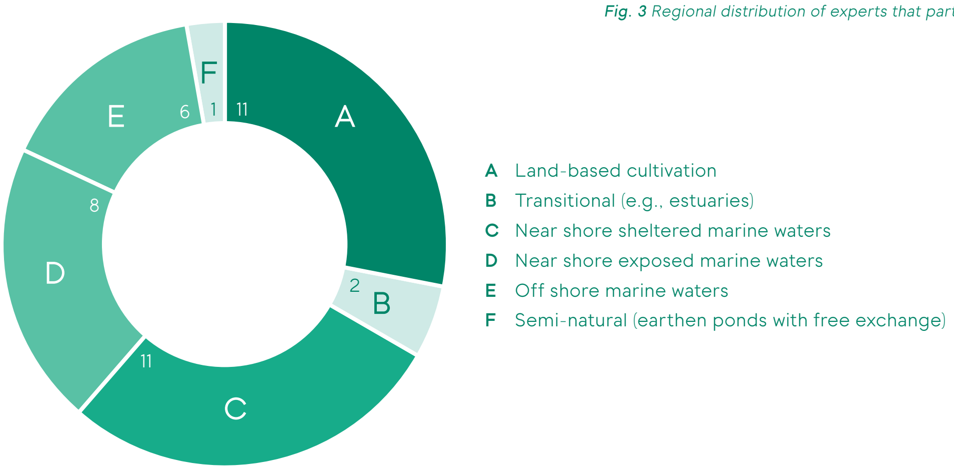


Fig. 4 Distribution of work experience in terms of types of seaweed cultivation among experts that participated in the Delphi questionnaire

4.2.2 Main Ecosystems Services identified by the Delphi respondents

According to the responses of the Delphi questionnaire, 85 % of the ecosystem services (ES) identified by the experts for seaweed cultivation fell within the "Regulation and Maintenance" category, based on the CICES 5.1 Classification (Fig. 5). Only 12% of ES identified were classified in the "Provisioning" category, and 3% were classified as "Cultural".

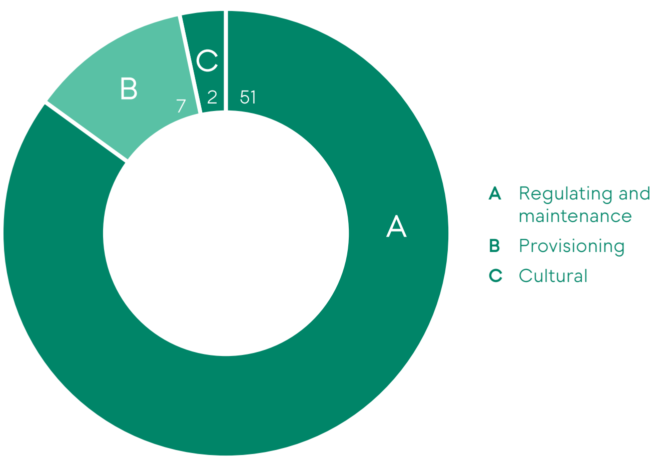
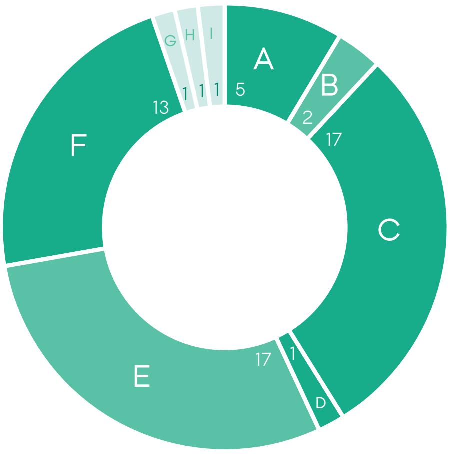


Fig. 5 Overview of relevant ecosystem services (general categories based on the CICES 5.1 classification) according to the expert responses to the Delphi questionnaire

A further breakdown of the responses (Fig. 6), still using CICES 5.1 classification, shows that the most referred ES provided by seaweed cultivation belong to the following classes: "Regulation of chemical composition of atmosphere and oceans (code 2.2.6.1) " and "Filtration/ sequestration/ storage/ accumulation by microorganisms, algae, plants, and animals (code 2.1.1.2)" both with 17%, followed by "Maintaining nursery populations and habitats, including gene pool protection (code 2.2.2.3) with 13%.

During the second round of the Delphi process, in reply to Question 1, respondents were asked to rank the top five ES: "From the list of Ecosystem Goods and Services (ES) presented below, please select the five that you feel are most important and rank them from 1 to 5, where 1 is the most important and 5 is the least important of the options selected". The average ranking is presented below (Table 2), whereas a higher score indicates higher importance. These results confirm only partially those of the first round. In fact, while in the first round the most referred ES were within the "Regulating & Maintenance" (85%) category, in the second round the most important ES related to "Provisioning" (in 2 of the top 3). ES such as recreation and tourism, education and training, and coastal protection were ranked as the least important by the experts (Table 2).



A Cultivated plants grown for nutritional purposes by in- situ aquaculture
B Cultivated plants (including fungi, algae) grown as source of energy
C Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants and animals
D Hydrological cycle and water flow regulation (including flood control)
E Atmospheric composition and conditions
F Maintaining nursery populations and habitats (including gene pool protection)
G Perst control
H Characteristics of living systems that enable education and training
I Elements of living systems for entertainment or representation

Fig.6 Overview of specific ecosystem services provided by seaweed cultivation according to the experts' responses to the Delphi questionnaire.

Table 2 Average scores of the ES, for Question 1, ranked from higher to lower importance, according to the respondents selected option. Individual ranking was set from 1 to 5, whereas higher score indicates higher importance.

ECOSYSTEM SERVICE	AVERAGE SCORE
Macroalgae grown for food (including hydrocolloids)	3.8
Regulation of water quality (including eutrophication, bio- mitigation, bioremediation)	3.2
Macroalgae grown for feed	2.7
Maintaining nursery populations and habitats (including gene pool protection)	2.0
Carbon sequestration/storage/accumulation by macroalgae	1.3
Climate regulation (CO2, carbon cycle, DMS, other)	1.3
Macroalgae grown as a source of energy	0.5
Pest and disease control	0.2
Coastal protection (erosion, wave reduction, flood control)	0.0
Characteristics of living systems that enable education and training	0.0
Elements of living systems used for recreation and tourism	0.0

4.2.3 Constraints identified by the Delphi respondents

Participants also responded to the question regarding the main constraints that need to be resolved before significantly upscaling macroalgae cultivation (Annex 2). The responses from the first round were grouped according to the PESTEL analysis (Fig. 7). Three categories equally stood out: legal (e.g., safety regulations), economic (e.g., lack of demand for seaweeds in many countries) and technological (e.g., production at large scale) and represented almost 70% of the total responses. According to the responses received, the less important constraints were related to social and environmental issues, representing 10% and 8%, respectively. Political constraints (e.g., political development and permitting) were identified in eight responses and represented 15% of the total.

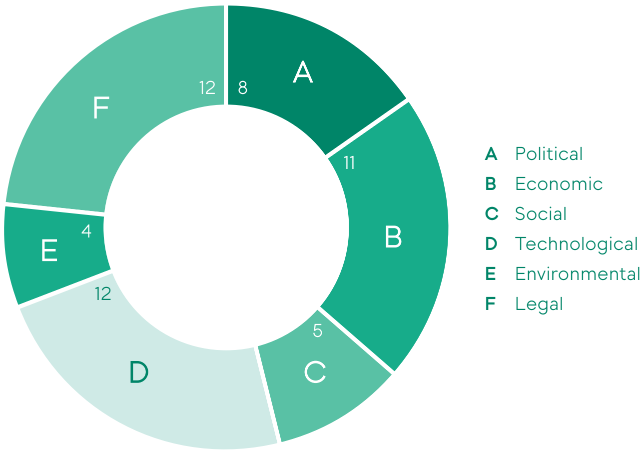


Fig.7 Distribution of constraints identified during the first round of the Delphi process among the PESTEL categories.

4.2.4 Negative impacts according to Delphi respondents

When asked what negative impacts or trade-offs upscaling macro-algae cultivation may lead to, particularly when it comes to ES, experts provided diverse responses, which are summarised below in Table 3.

In the second round of the Delphi process, the participants were asked to rank the negative impacts: "From the list of negative impacts or trade-offs that may result from upscaling of macroalgae cultivation (as identified in the previous round of questions) please select the five that you feel are most critical and rank them from 1 to 5, where 1 is likely to be the most severe and 5 is likely to be the least severe of the options selected".

The weighted scores associated with each impact show that 'Conflict with other users/uses' was the most important negative impact of macroalgae cultivation, identified by the experts, followed by 'Unknown environmental impacts' (Table 4). Physical damage (resulting from the farm structure) and reduction of water flow were ranked as the least important.

Table 3 Clustering of examples of potential negative impacts or trade-offs of seaweed cultivation provided by experts that participated in the first round of the Delphi questionnaire.

NEGATIVE IMPACTS PROVIDED BY EXPERTS
Excessive nutrients removal (e.g., compromising other ecosystem functioning, impacting the food web)
Carbon capture (e.g., excessive removal and impact on final destination, such as sinking)
Destruction of habitats (e.g., shading; clearing up the seafloor using anchor/stakes)
Decrease species diversity/biodiversity
Spreading diseases and pests
Impacts on tourism (e.g., plastics, casted biomass, visual impact, etc.)
Decrease water quality (e.g., pollution during farming operations, materials, debris, etc.)

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Table 4 Negative impacts, identified by the experts during the first round of the Delphi process and ranked during the second round

POTENTIAL NEGATIVE IMPACT OR TRADE-OFF	AVERAGE SCORE
Conflict with other users/uses (at land or sea)	3.17
Unknown environmental impacts (e.g., on deep sea, benthic and pelagic ecosystems)	2.50
Mismatch in supply and demand of biomass	2.00
Shifts in seaweed genetic diversity	2.00
Pollution (e.g., plastics)	1.50
Negative impacts on ecosystem biodiversity	0.83
Aesthetics	0.83
Over exploitation of the environment	0.83
Water flow reduction	0.67
Physical damage (e.g., damage to the sea floor resulting from the farming structures, anchors, stakes, etc.)	0.67

4.2.5 Main knowledge gaps according to Delphi respondents

In reply to the question: "What are the knowledge gaps on macroalgae cultivation (e.g., processing and marketing), that would need to be addressed in order to upscale it and enhance its delivery of ES?", the respondents to the questionnaire mentioned a number of topics, which the EWG grouped into categories listed in Table 5. It should be noted that the answers provided were often not formulated as a knowledge gap; instead, the experts mentioned one or more terms related to a knowledge.

The EWG have refrained from reformulating the answers, to avoid incorrect interpretation. All knowledge gaps, or hints at knowledge gaps, were categorised using the PESTEL framework in Table 5. The results presented in Fig. 8 show that the highest number of knowledge gaps identified by the experts fell within the 'Technological' category, followed by 'Economic'.

Table 5 Knowledge gaps identified during the first round of the Delphi process, with associated PESTEL category and count (number of experts that identified each specific knowledge gap).

TERM RELATED TO A KNOWLEDGE GAP	PESTEL CATEGORY	TOTAL COUNTS
Biofouling (1), Density (1), Drying/stability/pre-processing (4), Consistent production quality (2), Strain improvement for quality and consistency (2), Farming technology (1), Year-round crop to enable uptake of nutrients and achieve a stable secondary ecosys-tem around fish farms (1), Mechanization (1), Land-based cultivation (1), Evaluate near- and offshore farm grounds (1),	Technological	15
Suitable price (1), Transparency market prices (1), Business case (2), Upscaling of farms to km2 size (1), Production in large-scale (2), Moving offshore for more space (1), Detailed market information (1)	Economic	9
CO2 credits, Biodiversity credits (1), Change politics (1), Set legal standards for heavy metal maximum values (1), Mechanisms for valorisation of ecosystem services (1)	Political	4
Ecosystem carrying capacity (3), Insight into scale-effects (1)	Environmental	4
Training of young scientists (1), Direct links between farmers and processors (1)	Social	2


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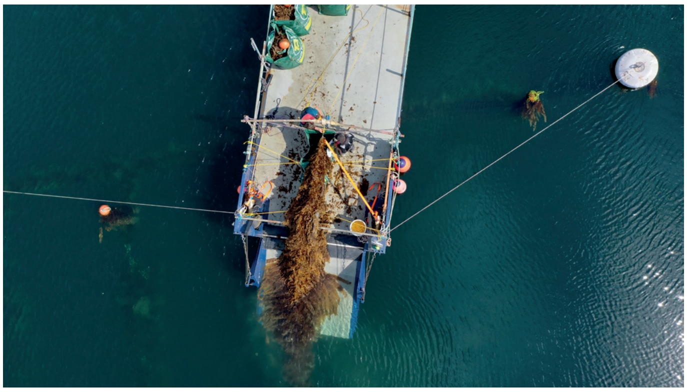
Ulva compressa *in aerated bottle cultivation.*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Harvesting *of Saccharina latissima, west coast of Scotland.*

In the second round, the participants were asked to rank the knowledge gaps based on importance: "From the list of knowledge gaps presented below, please select the five that you feel are most important and rank them from 1 to 5, where 1 is the most important and 5 is the least important of the options selected".

The weighted scores of knowledge gaps (Table 6) suggest to confirm the importance attributed to the Technological Knowledge Gaps, such as "farming technologies", and "technologies for macroalgae processing", followed by Market Data (including sub-categories belonging to the Economics, Technological and Social divisions of a PESTEL analysis). Economic and Political aspects are the following categories of knowledge gaps and Environmental assumes less importance in the ranking according to the respondents, with 'Training' as the least important.

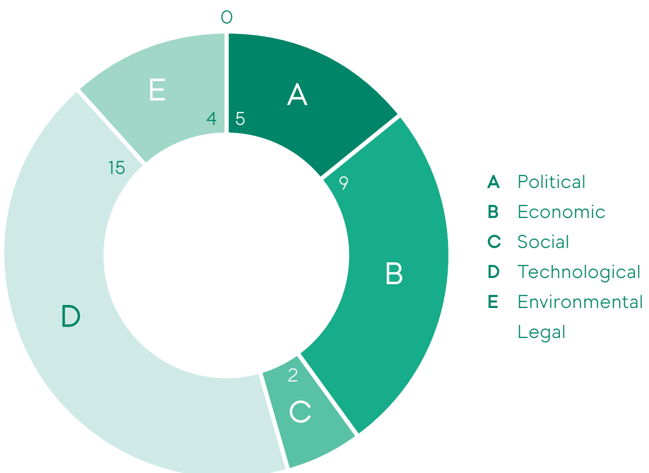


Fig.8 *Knowledge gaps identified during the first round of the Delphi process grouped by PESTEL categories (as in Table 5). Note that there is no knowledge gap related to the legal category.*

Table 6 Knowledge gaps identified during the first round and ranked during the second round of the Delphi process.

KNOWLEDGE GAPS CATEGORY	AVERAGE SCORE	SUB-CATEGORIES
Farming technologies	2.3	■ Strain improvement ■ Ensure consistent production quality ■ Develop mechanisation; ■ Technologies for further cultivation approaches
Technologies for macroalgae processing	2.0	
Market data	1.67	■ Adequate value-chain connections ■ Detailed market information ■ Adequate price
Economic data	1.5	■ Appropriate business cases ■ Information on valorisation of ES
Politics	0.8	NA
Data obtained from "real" macroalgae farming	0.8	■ Appropriate scale of production ■ Appropriate spatial planning for farming sites
Environmental data	0.3	■ Nutrient uptake/bioremediation ■ Biodiversity impact ■ Occurrence/impact of nuisance species
Certification	0.3	■ CO_2 footprint ■ Food safety ■ Ecosystem provisioning
Training	0.0	NA

It is interesting to notice the lower importance attributed to knowledge gaps concerning Environmental Data, when compared to Technological and Economic knowledge. Even though the question specifically asked for knowledge gaps that could help to upscale macroalgae production and enhance its ES deliveries, and that several ES directly related to "Regulation & Maintenance" and "Provisioning", many responses were related to knowledge gaps that can be considered in the Technological and Economic categories.

In reply to the request to provide some possible means (actions and/or key players) to address critical knowledge gaps, the following **suggestions were provided by the respondents:**

- Authorities that provide permits for farming, connecting them in the EU to harmonise the rules.
- Enable large scale test sites by connecting the projects to independent institutions following the effects.
- Include Lloyds to learn about the risks. De-risking in all aspects is essential for further upscaling.
- Seaweed cultivation must enter the political agenda to create funds that will support farmers developing novel technologies and automation in production and processing. This will ensure consistent production quality.
- The EU should be a key player in funding research and technology specifically in addressing these knowledge gaps, both through general and industry pointed financing actions, including more COST actions.
- Totally dependent which country you live, no point providing this as state agencies, dept. of marine or Universities are responsible.

Once again, in this case the EWG decided not to rephrase the respondents' answers, in order to avoid any bias. In this case, it is worth noting that even though the main knowledge gaps are in the Technological category, many of the suggestions are related to Political issues, either through funding decisions, licensing aspects (namely country harmonisation) and planning.

QUICK SCOPING REVIEW

5 Quick Scoping Review

5.1 Methodology

A Quick Scoping Review (QSR) is a systematic and objective study of evidence from scientific literature, which aims to provide an informed conclusion on the volume and characteristics of an evidence base and a synthesis of what that evidence indicates in relation to a question. In order to reduce the time and expense of production, this method does not include a critical appraisal of the evidence. The lack of a critical appraisal limits the use of this methodology to directly inform a decision, but provides a general understanding of the evidence base, which is useful to inform general policy direction (Collins et al., 2015). In the present study, a quick scoping review was conducted (Collins et al. 2015) to identify peer-reviewed English language scientific journal articles, addressing ES provided by macroalgal cultivation. The scoping review was carried out to summarise the current state of the knowledge and identify potential constraints and knowledge gaps. For this purpose, documents were screened in three different steps (identification, screening, eligibility; Fig. 9).

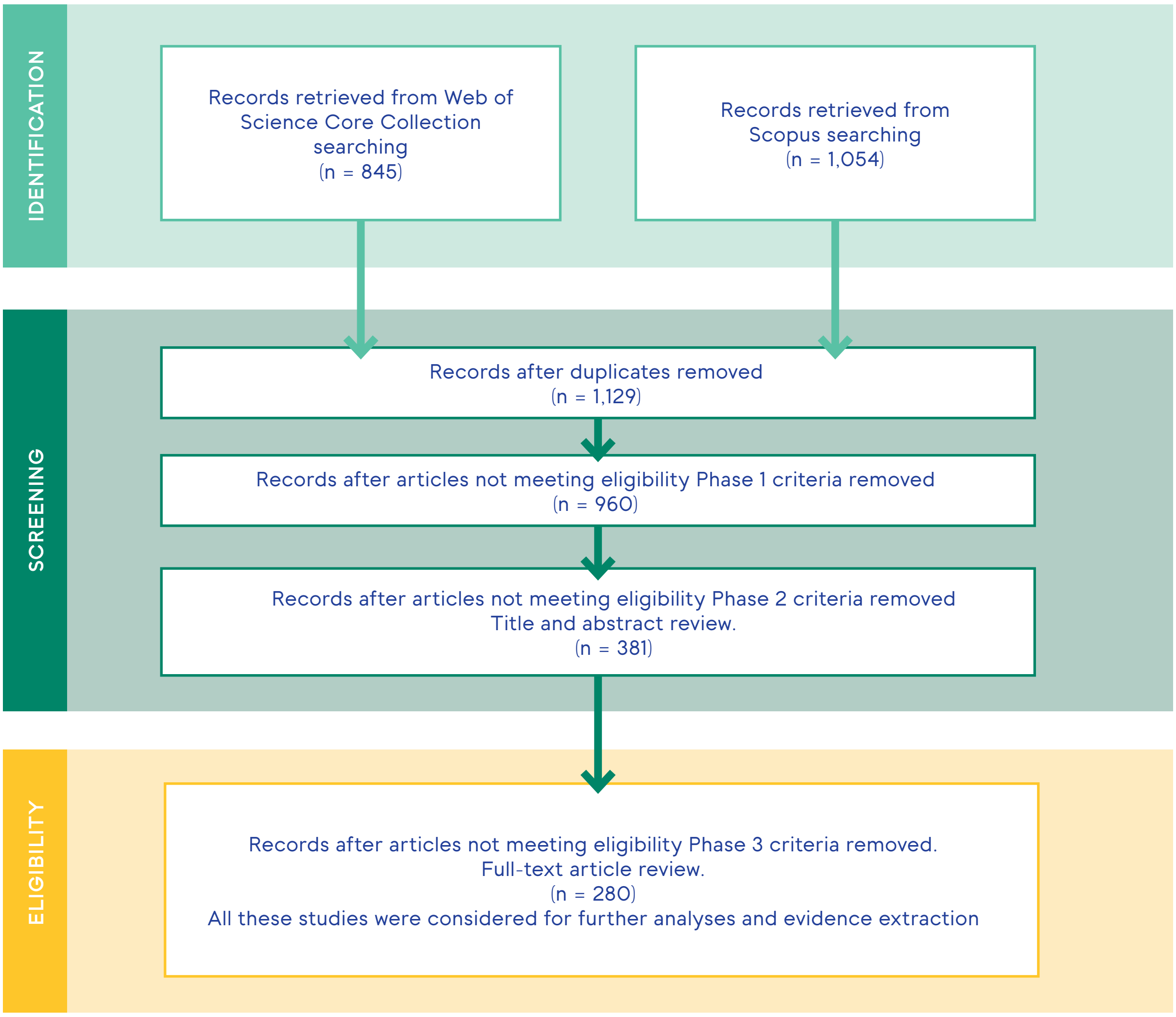


Fig.9 Diagram showing the different steps during the quick scoping review and the number of manuscripts that were finally considered eligible.

5.1.1 Step 1 – Identification

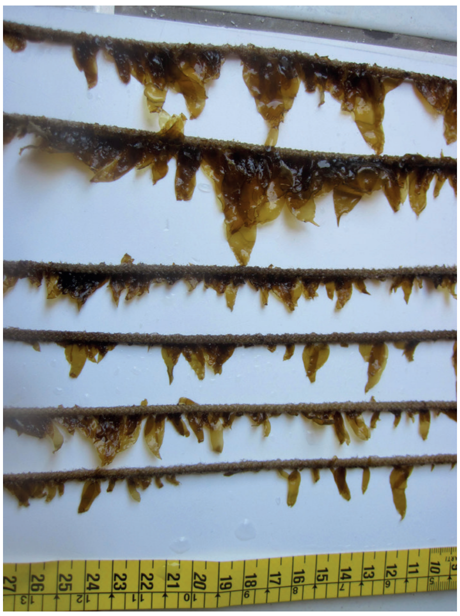
In the first step, we conducted a structured search of the scientific literature. A preliminary exploration of the literature, based on 5 primary keywords (Macroalgae, Seaweed, Cultivation, Farming, Aquaculture) and 11 secondary keywords (climate change, invasive species, impacts, arsenic, bromine, ecosystem services, greenhouse, value chain, biosecurity, carbon, bioremediation) using the web search engine Google Scholar resulted in 442 papers. However, a further broader search was carried out, due to concerns of potentially missing important papers, as result of keyword restrictions and the general nature of ecosystem services. Consequently, new keywords were defined, based on six combinations of the primary terms "macroalga" and "seaweed", and the secondary terms "cult*", "farm*" and "aquaculture", whereas quotation marks were used for combination and search to reduce the number of unrelated literature. The search was conducted in parallel in Scopus and Web of Science (WoS) database, on 16th June 2021. Data was compiled in Mendeley (reference management software) and duplicates were removed using the software, **resulting in a total of 1,229** entries (Table 7).

Table 7 Outcome of literature search of the six keywords in Scopus and Web of Science (WoS) database in June 2021.Amount of totals include data set after software and subsequent manual duplicate removal.

KEYWORD	SCOPUS	WOS
Seaweed aquaculture	136	227
Seaweed farm*	363	266
Seaweed cult*	620	348
Macroalgae* aquaculture	15	15
Macroalgae* farm*	22	18
Macroalgae* cult*	103	96
Total with duplicates in each data base (by software check)	1,259	970
Total without duplicates in each data base	1,054	845
Total after removing duplicates	**1,229**	

© Elisa Capuzzo

Cultivation *of Kappaphycus in the Philippines.*



© Tânia Pereira

Lines seeded *with juveniles sporophytes of Sacarina latissima*

5.1.2 Step 2 – Screening

The resulting entries were sorted in an Excel spreadsheet with macros, containing information on bibliography type, author, title, DOI, publication year and abstract. All articles were sorted and screened according to formal criteria defined in an exclusion/inclusion table (Table 8 Phase 1) identifying 960 articles to be assessed in Phase 2. All articles fulfilling the formal criteria of Phase 1 were randomly assigned and assessed by the different experts in the working group, who decided based on title and abstract and defined criteria (Table 8 Phase 2) whether the article should be included or excluded.

After Phase 2, the 381 remaining articles were assessed again following the same criteria as in Phase 2, but based on the full text, which resulted in a total of 280 articles. These 280 articles provided the base of the following analytical part of the QSR and are listed in References forming the base of the QSR. To avoid potential bias by individual decisions during Phases 2 and 3, the eligibility of each article was assessed by two experts. In case of disagreement, a third expert assessment was conducted to determine if the article was eligible or not.

Table 8 Summary of exclusion and inclusion criteria used in Phases 1 (formal criteria) and 2 (title and abstract review) of the Quick Scoping Review

EXCLUSION CRITERIA	INCLUSION CRITERIA
Phase 1: Formal criteria	
Non-English	English
Before 2000 or after 06/2021	Between 01/2000 and 06/2021
Non original articles	Peer-reviewed original articles
Non available in SCOPUS or WoK	Available in SCOPUS or WoK

EXCLUSION CRITERIA	INCLUSION CRITERIA
Phase 2: Title and Abstract / Phase 3: Full text	
No seaweed aquaculture	Seaweed aquaculture
Laboratory experiments (<100 L)	Aquaculture systems (>100 L)
Focus on functions	Focus on services
New methodologies or products	Assessment of actual services
Weak link with seaweed aquaculture	Risk & Disservices of seaweed aquaculture
Optimization EOs techniques	Spatial and temporal assessment of seaweed aquaculture
Description of associated biodiversity to seaweed aquaculture	Studies on the biotic interplay related to seaweed aquaculture

5.1.3 Phase II - Classification

To provide a general insight of the volume and characteristics of the evidence found in the scientific literature, the eligible articles were classified in different categories, included as columns in the Excel spreadsheet with macros. These categories addressed the classification of the different articles, according to 1) species, 2) country, 3) scale, 4) sector, 5) PESTEL analysis, 6) aquaculture type, 7) study protocol, 8) farm size; as well as their contribution, to different ecosystem services (ES: 9) provisioning, 10) regulating and maintenance, 11) cultural; based on CICES Classification v 5.1. (Haines-Young and Potschin-Young 2018). Corresponding cells were partly filled via pre-formulated drop-down menus to ease classification, whereas a separate specification column allowed the expert to provide additional information. For the review findings, the columns 12) knowledge gaps, 13) identified constraints, 14) disservices, 15) disservices comments and 16) expert notes were also provided. An overview of all categories with corresponding subcategories are presented in Annex 3.

Scientific papers selected for inclusion from Phase 1 were randomly assigned to experts of the working group and classified. A synthesis of the literature reviewed using the QSR method is presented in the following section. Results refer to QSR literature provided in the References.

5.2 Data Synthesis

The geographic regions that dominated the studies included in the QSR were Asia (30%), Europe (24%) and Oceania (23%). Fewer studies were conducted in Latin America (11%) and Africa (7%), and fewer still in North America (4%) (Fig.10A). Only 3% of the studies screened conducted a global analysis of seaweed cultivation. In terms of the total number of eligible articles identified by year of publication, an increasing trend was observed from 2000 to 2020, with over 45 eligible articles published in 2020 (Fig.10B). The marked decrease in 2021 reflects the fact that only articles published before June 2021 were considered.

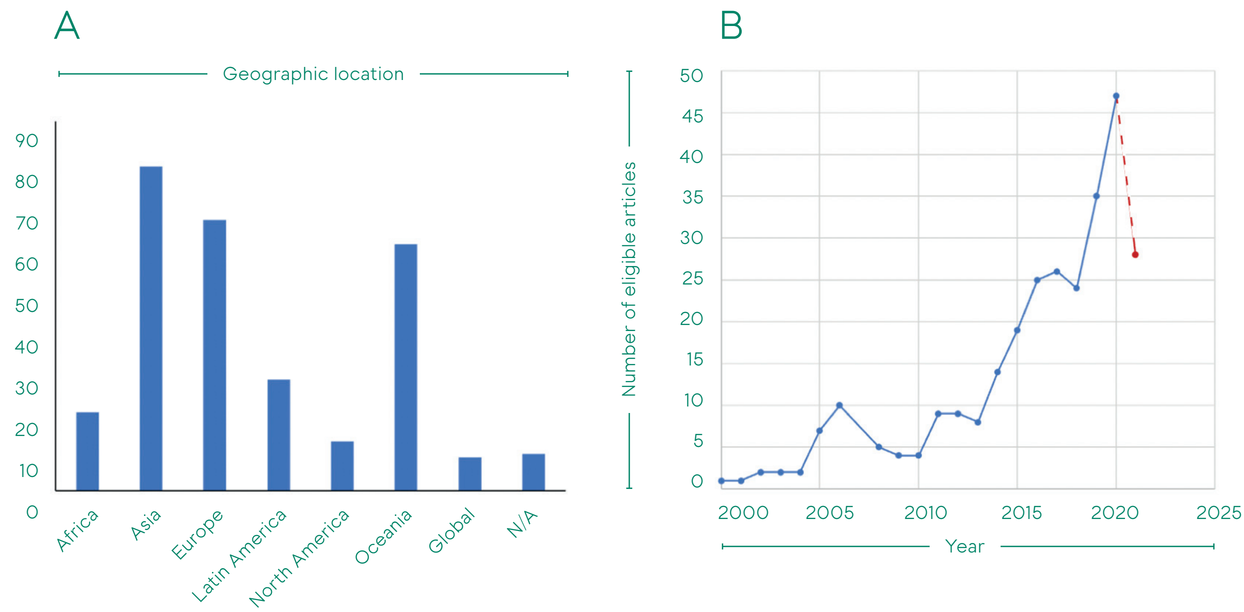


Fig.10 Number of eligible articles identified in the QSR A) sorted by geographical region and B) by year of publication. The red dotted line corresponds to the year 2021, where only half of the year (to mid June) was considered for the QSR.

5.2.1. Cultivated macroalgal species

Of the 280 studies reviewed in the QSR, 213 considered a total of 37 macroalgae genera comprising 77 species. In studies focusing on European Waters (Table 9), we found 17 different species, with *Saccharina latissima* as the most highly studied (59% of the considered studies), followed by *Laminaria digitata* (14%) and *Alaria esculenta* (11%). Nevertheless this has to be interpreted with caution, due to potential taxonomic mismatches. Species names were validated according to the taxonomic data base algaebase (Guiry and Guiry 2022). For analysis, the different seaweed taxa were categorised into the following six taxonomic/functional groups:

i) *Porphyra/Pyropia* (about three genera and four species: *Pyropia sp.*, *Porphyra umbilicalis*, *Neopyropia tenera*, *N. yezoensis*).

ii) Eucheumatoids (two genera comprising about three species: *Eucheuma denticulatum*, *Kappaphycus alvarezii*, *K. striatus*).

iii) Gracilarioids (two genera comprising about 18 species: *Gracilaria birdiae*, *G. bursa-pastoris*, *G. cervicornis*, *G. changii*, *G. chilensis*, *G. cornea*, *G. conferta*, *G. domingensis*, *G. edulis*, *G. gracilis*, *G. parvispora*, *G. tenuistipitata*, *G. textorii*, *G. tikvahiae*, *G. vermiculophylla*, *Gracilariopsis chorda*, *G. lemaneiformis*, *G. longissima*).

iv) Ulvoids (one genus comprising about 10 species: *Ulva australis*, *U. clathrata*, *U. compressa*, *U. intestinalis*, *U. lactuca*, *U. ohnoi*, *U. prolifera*, *U. pseudorotundata*, *U. reticulata*, *U. rigida*).

v) Kelps (order Laminariales- eight genera comprising about 11 species: *Alaria esculenta, Ecklonia maxima, E. cava subsp. stolonifera, Laminaria digitata, L. farlowii, Lessonia trabeculata, Macrocystis pyrifera, Nereocystis lutkeana, Saccharina latissima, S. japonica, Undaria pinnatifida*).

vi) Other (21 genera about 31 species: *Anadyomene stellata, Asparagopsis armata, A. taxiformis, Blidingia sp., Caulerpa lentillifera, C. racemosa, Chondracanthus teedei, C. chamissoi, Codium fragile, C. taylorii, Chaetomorpha sp., Cladophora sp., Derbesia tenuissima, Dictyota ciliolata, Furcellaria lumbricalis, Gayralia sp., Gelidium amansii, Hypnea musciformis, H. pseudomusciformis, Padina australis, Palmaria palmata, Rhizoclonium sp, Sargassum aquifolium, S. fusiforme, S. liebmannii , S. platycarpum, S. siliquosum, S. wightii, Spirogyra sp., Turbinaria conoides, Ulothrix sp.*).

Table 9 *Species cultivated in Europe for commercial or research purposes identified in the QSR. *- considered as non-native species. Note that some studies referred to more than one species.*

	SPECIES	STUDIES (%)
1	*Ulva intestinalis*	4
2	*Ulva lactuca*	2
3	*Ulva rigida*	4
4	*Ulva rotundata*	5
5	*Asparagopsis armata**	4
6	*Asparagopsis taxiformis**	2
7	*Chondracanthus teedei*	4
8	*Furcellaria lumbricalis*	2
9	*Gracilaria bursa-pastoris*	2
10	*Gracilaria gracilis*	4
11	*Gracilaria vermiculophylla**	2
12	*Gracilariopsis longissima*	5
13	*Palmaria palmata*	4
14	*Alaria esculenta*	11
15	*Laminaria digitata*	14
16	*Saccharina latissima*	59
17	*Undaria pinnatifida**	5

Figure 11A shows the number of studies from the QSR that provided data on each seaweed taxonomic/ functional group. About one third (32%) of the studies focused on kelps, mainly represented by the genus *Saccharina* (*S. latissima, S. japonica*), followed by Euchematoids (28%), and the Gracilarioids (22%), mainly represented by the genus *Gracilaria*, followed by the Ulvoids (15%) and *Porphyra/Pyropia* (8%). Some studies did not specify a seaweed taxa, in which case they were assigned to the category "other". Regarding the regional distribution of the studied seaweed groups, most of the studies were focused on Euchematoids in Africa and Oceania, and on kelps in Europe and North America (Fig.11B). In Asia and Latin America, the research efforts were more evenly distributed between the different seaweed groups. It should be pointed out that most of the studies focused on Porphyra/Pyropia were developed in Asia.

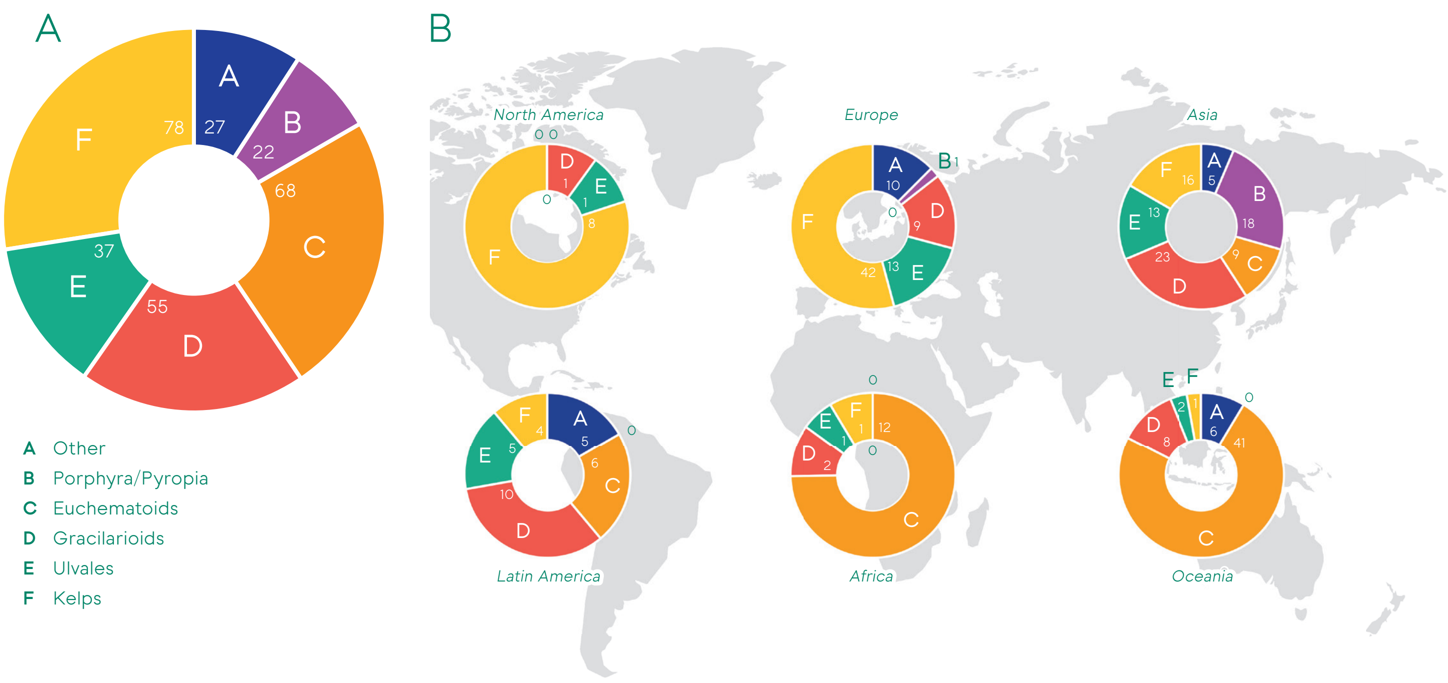


Fig.11 Percentage contribution of the different seaweed taxonomic/functional groups A) within the literature identified in the QSR (n =241) and B) at the global and continental (i.e. Africa, Asia, Europe, Latin America, North America, and Oceania) scale.

5.2.2 Seaweed farms

The majority of studies (61%) were conducted in nearshore seaweed farms. Land-based seaweed cultivation was represented in 12% of studies, while offshore seaweed cultivation was represented in 6% of studies. In many cases of farms located close to the coast or in estuarine environments, it was not possible to determine if farms were located in transitional water (with important fluctuations in salinity), or coastal areas sheltered or exposed to the wave action. For this reason, the three categories previously defined (i.e. nearshore, sheltered; nearshore, exposed; and transitional) were merged in one category named nearshore (Fig.12).

Regarding the scale, the size of the seaweed farms were not reported in many studies (34%). Among studies where the scale of seaweed cultivation was reported, 39% were on a pilot or small scale, and 27% were considered medium or large scale. Most of the studies developed in offshore aquaculture facilities were developed at large scale (44%), while in the case of land-based studies most of them were developed at small scales (68%). Regarding the scale of studies developed in nearshore farms, most of them were developed at small scales (46%) followed by large scale studies (36%).

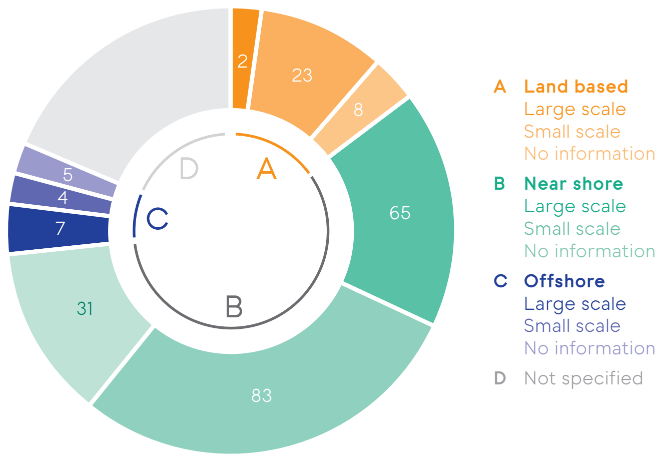


Fig.12 Overview of the types and scales of seaweed cultivation that were identified during the Quick Scoping Review. See the Methods Section for the definition of each cultivation type and size.

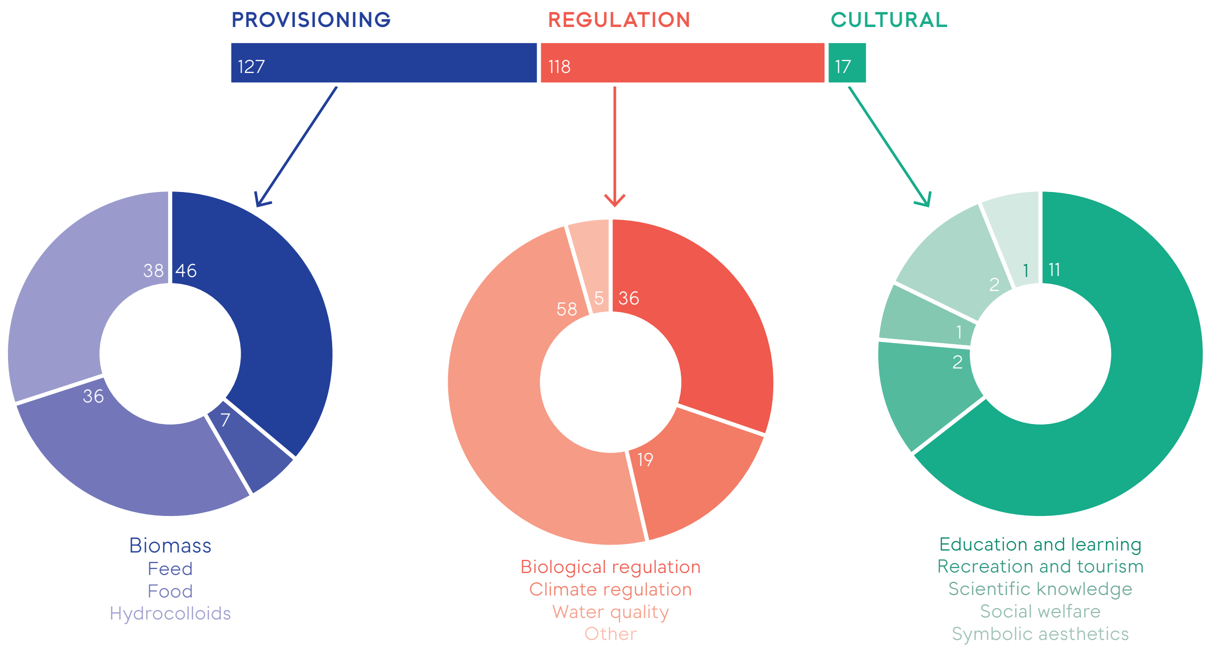


Fig.13 Overview of the number of studies identified through the Quick Scoping Review that provided evidence of ecosystem services provided by seaweed cultivation based on the CICES classification, and the details for each one of the three categories (Provisioning, Regulation and Cultural) of Ecosystem Services.

5.2.3 Ecosystem Services
a. Ecosystem Service Classification

The QSR resulted in 214 studies giving evidence of ES provided by seaweed cultivation. Please note that in some studies evidence for more than one ES were found. 'Provisioning' (49%) and 'Regulation and Maintenance' (45%) services were identified as the two main categories of ES provided by seaweed cultivation, but cultural services were also represented (Fig. 13).

Within the 'Provisioning' services classification, biomass (food) was the most common (36%) ES provided by seaweed cultivation, followed by hydrocolloids (30%), food (28%), and lastly feed (6%; Fig. 13). The QSR showed that the ES most often provided by seaweed cultivation within the 'Regulation and Maintenance' classification was water quality improvement. The QSR also identified studies (31%) that provided evidence of diverse types of biological regulation and climate regulation (16%; Fig. 13).

Results of the QSR showed that the 'Cultural' services provided by seaweed cultivation include education and learning, recreation and tourism and social welfare (Fig. 13). The educational/ learning aspect of seaweed culture has provided a viable livelihood source in marginalised coastal communities of countries, such as the Philippines, India or Indonesia (269, 273, 105). The activity can promote inclusiveness and gender equality and the studies have pointed out increased awareness to conserve coastal ecosystems. However, there are also constraints (e.g., marketing limitations, farm ownership, climatic risks) to further develop seaweed farming industries.

Some of these constraints can be successfully overcome with the help of specific training workshops and technical guidance (195). Seaweed farming has also been perceived as a tourism product in developing countries (103) to enhance the socio-economic status of the community. Macroalgae culture can have social meaning beyond the economic activity in coastal communities, particularly when the activity dignifies the role of women in society (43), however, several documents highlight the need to address working conditions and power imbalances to provide safe and fair social and economical development (66). Evidence of seaweed cultivation providing the ecosystem services of scientific knowledge and symbolic aesthetics could only be found in single studies, suggesting that more studies are needed to assess the cultural ES provided by seaweed cultivation.

Analysis of the ES provided by seaweed taxa (Fig. 14) showed that kelp, as well as the Gracillarioids and the Ulvoids, as strongest represented taxa, were mainly considered to regulate water quality (29%, 42% and 41% of total ES, respectively), besides providing food and biomass used for other purposes, whereas the Eucheumatoids were mainly considered for hydrocolloid production (45% of total ES) .

This suggests that the different groups of taxa seem to provide different ecosystem services in different proportions, and therefore a monoculture on a large-scale would not provide the greatest amount and diversity of ES. Rather, a combination of different species grown at scale could provide the greatest diversity and number of ES in Europe.

ECOSYSTEM SERVICES BY TAXA

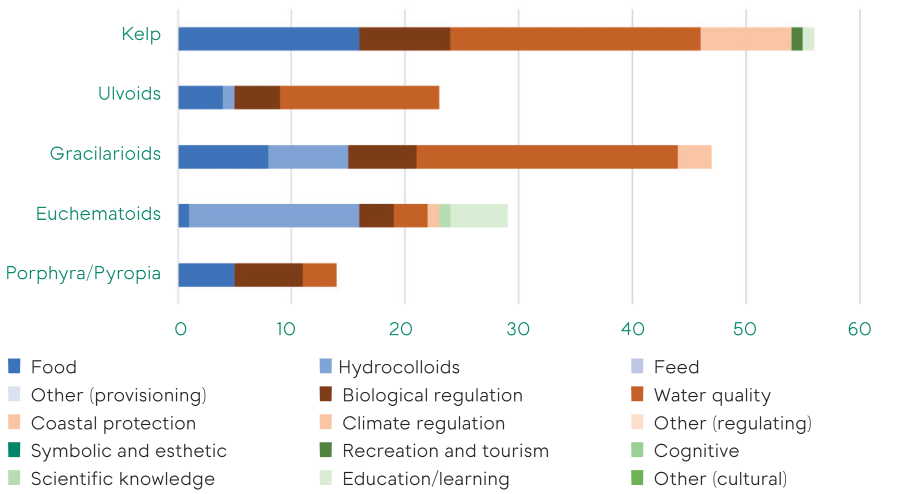


Fig.14 Ecosystem services (classification and service type) provided by different groups of seaweed taxa based on results from the Quick Scoping Review. The x-axis shows the number of studies that showed evidence of ecosystem services provided by each taxa. Bluish colours refers to provisioning services, reddish colours to regulating services, and greenish colours to cultural services.

b. Ecosystem Services and the United Nations Sustainability Goals

If the variety of ecosystem services provided by seaweed cultivation based on the results of the QSR are considered within the context of the United Nations Sustainable Development Goals (U.N. 2015), it is evident that many of the UN SDGs are addressed by seaweed cultivation (Fig.15). Most notably, goals 14 (life below water), 11 (sustainable cities and communities) and 12 (responsible production and consumption) are most often addressed by seaweed cultivation. More specifically, seaweed cultivation contributes to the target to prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution and to increase scientific knowledge, develop research capacity and transfer marine technology within SDG 14. The bioremediation services provided by seaweeds also closely link to SDG 6 (clean water and sanitation), considering the interconnections between marine, estuarine and fresh-water systems and that bioremediation of marine waters can contribute to sustainable management of water resources and supplying access to safe water and hence, unlocking economic growth and productivity. The target to protect the world's cultural and natural heritage via sustainable tourism within SDG 11 is also addressed. Additionally, seaweed cultivation can contribute to goals 2 (zero hunger), 3 (good health and well-being), 7 (affordable and clean energy), 10 (reduced inequalities), and 13 (climate action). Even the collaboration and efforts by the EWG for this request, including sharing knowledge and expertise, can be considered a contribution to global partnerships and sustainable development, according to SDG 17, target 17.16.

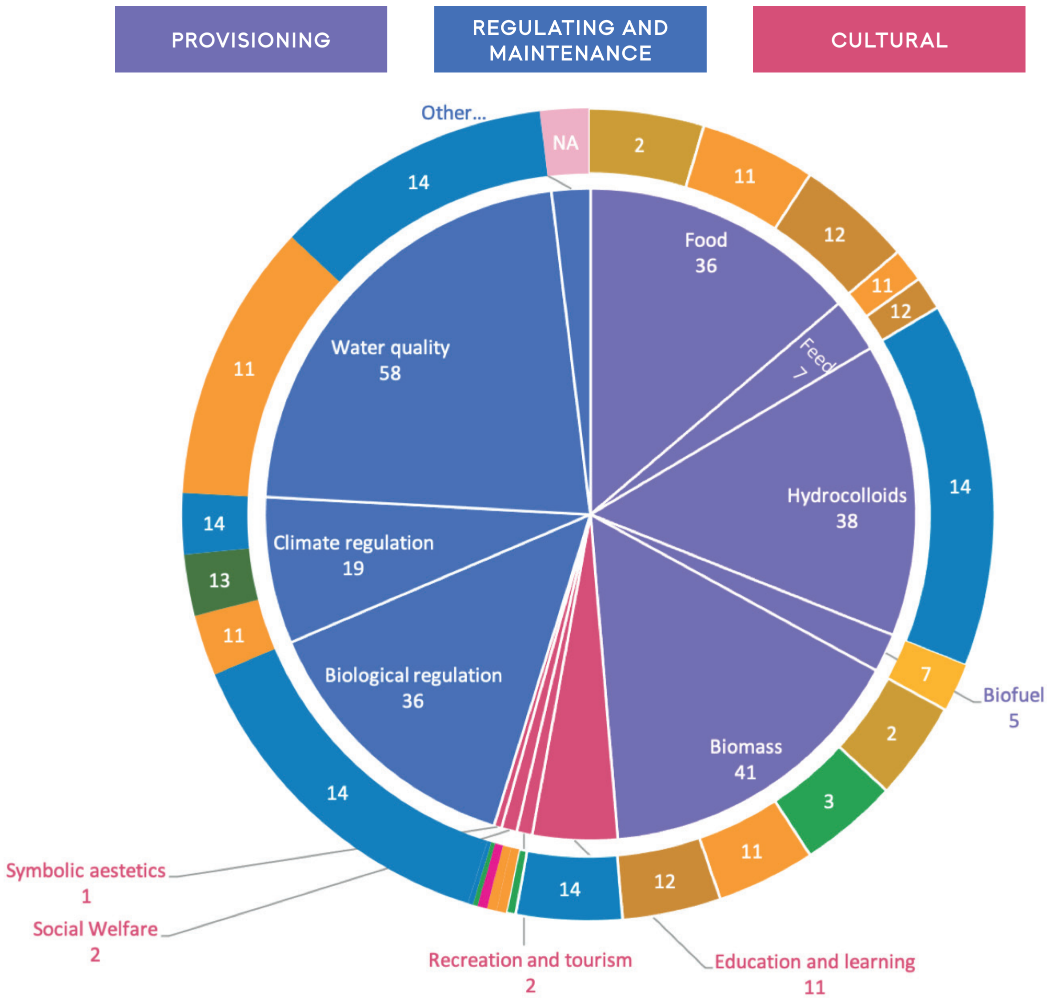


Fig.15 ES and SDGs provided by seaweed cultivation. Relationship between each type of ecosystem service provided by seaweed cultivation (inner pie chart) and the related United Nations Sustainable Development Goals (UNSDGs; U.N. 2015; outer doughnut. The inner pie chart shows the number of studies from the QSR that showed evidence that the named ecosystem service is provided by seaweed cultivation. The ecosystem services are colour-coded according to the CICES classification (Provisioning, Regulating and Maintenance or Culture Services). The outer doughnut shows the UNSDGs that are addressed by the associated ecosystem services provided by seaweed cultivation. The UNSDGs are colour-coded according to the original UNSDG logo and the goal numbers are shown, except in cases where the doughnut slice is too small (2- zero hunger, 3- good health and well-being, 4 - quality education, 7 - affordable and clean energy, 10-reduced inequalities, 11-sustainable cities, 12-responsible consumption and production, 13-climate action, 14-life below water).

5.2.4 Constraints

Within the analysed 280 studies, 143 (51%) studies identified a large number of constraints, which were classified within the different PESTEL categories related to seaweed culture. In addition, a further group ('Study') was identified to classify papers (35, equivalent to 12%) presenting constraints and weaknesses in their study design, such as limited length and scale of experiments/investigations and/ or limitations in the modelling/statistical approach adopted (Annex 4).

Main Constraints. As shown in Fig. 16, the key groups of constraint identified were environmental (40%) and technical (35%) , followed by constraints in the economic, social and political spheres. These different subcategories will be analysed in more detail below.

Environmental (Fig. 17). Within the environmental constraints, nuisance species were the most dominant group (28%), comprising organisms, growing either epiphytic on the fronds of cultivated species (e.g., 191, 129) decreasing their value (e.g., by encrustations); or attached to cultivation structures, forming blooms under favourable conditions, competing for light and nutrients (e.g., 55). This subgroup includes studies on associated planktonic microalgae (e.g., 31), as well as, studies on different pathogens causing diseases (e.g. ice-ice disease) strongly affecting the harvest quality and quantity (e.g., 18). The second most important environmental constraint identified was water conditions (24%), in which elevated nutrient concentrations play a crucial role in increasing algal growth (e.g., 277, 258), whereas sewage from cities may also contribute pollutants, which can negatively affect quality and production in seaweed farms (e.g., 275). Consequently, ambient water quality was considered a crucial criterion for seaweed farm site selection (e.g., 29, 210).

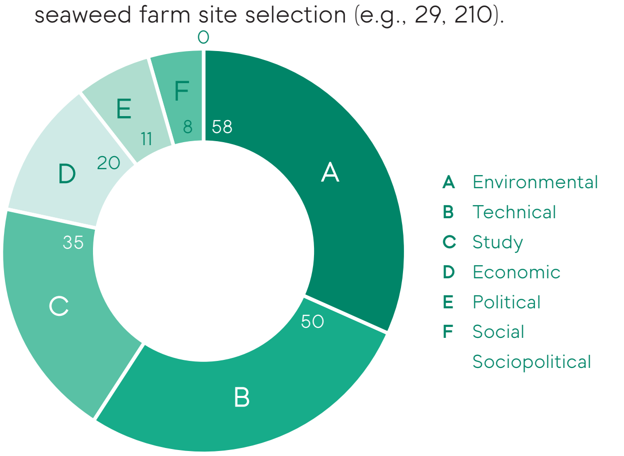


Fig.16 Classification of papers by constraint categories as described in Annex 4

The third identified constraint seasonality (17%) was listed, due to the importance of different seasonal driven changes (e.g., water temperature, light, nutrient availability), affecting the growth and chemistry of cultivated macroalgae (e.g., 65, 230). Biotic factors were also highlighted as strongly interacting with the growing bioresource (e.g., seasonal phytoplankton blooms, 255, 99). In addition, the presence of seaweed stocks can affect the local fauna, which finds a temporarily limited shelter and habitat in the farms (e.g., 249, 92). Further information on the other subgroups can be found in Annex 4.

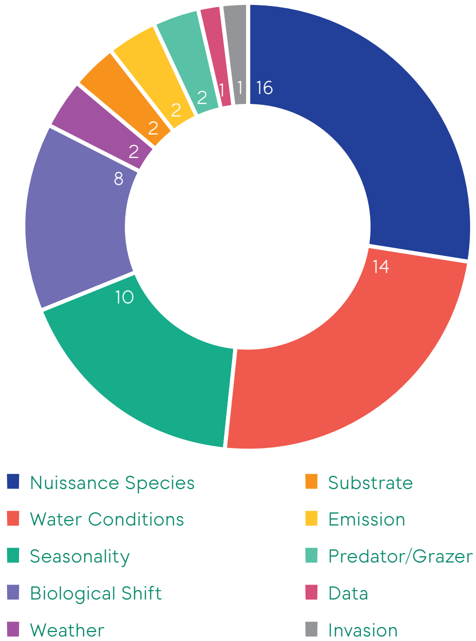


Fig.17 Overview of different environmental constraints as described in Annex 4

Technical (Fig.18). 'Technology' and 'Production' combined accounted for approximately half of the technical constraints identified (28% and 24% respectively). Examples of 'Technology' constraints included difficulties in implementing artificial upwelling to provide nutrients to seaweed farms (e.g., 57) and seaweed production at large scale (e.g., 58); need of developments in the production of low carbon seaweed ethanol (e.g., 109) and mechanisation of farming (e.g., 175). Technical constraints relevant to 'Production' included nitrate uptake and inhibition in seaweed (e.g., 200), investigations on the potential nutrient bio-mitigation capacity of seaweed farms, also in IMTA contexts (e.g., 112, 243). Constraints around technical aspects at the nursery stage were identified in 16% of the papers considered; these included strain selection (e.g., 185), intraspecific crossing between seaweed species (e.g., 276), nutrient uptake in tanks prior deployment of seaweed at sea (e.g., 87). Technical constraints in the context of product quality and post-harvest procedures and infrastructures were also reported in approximately 10% of the papers each. Brief descriptions of the other subcategories, to help differentiate between technological and production constraints, can be found in Annex 4.

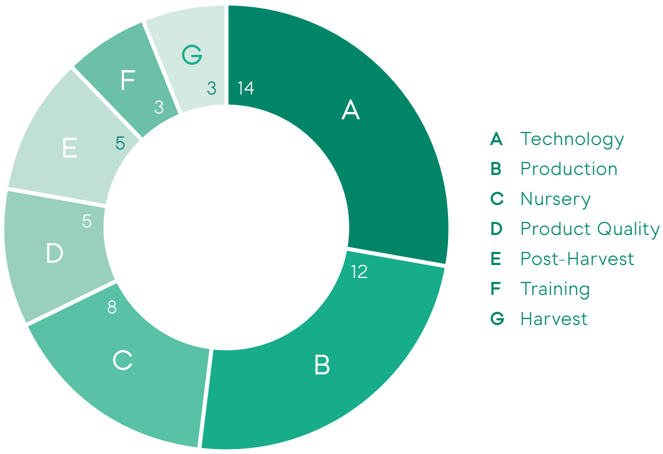


Fig.18 Overview of different technical constraints as described in Annex 4

5.2.5 Negative Impacts/Risks

The majority (212) of the papers reviewed did not investigate negative impacts or risks (Fig.19). Among those that did report negative impacts or risks, environmental impacts were of the highest concern. Examples of potential environmental impacts of seaweed aquaculture included unknown impacts on deep sea communities, impacts on benthic communities, particularly seagrass beds (however, this was mostly relevant in tropical regions and not in Europe) and competition for nutrients with pelagic ecosystems. Of second highest concern identified was the potential of seaweed aquaculture to create large-scale macroalgal blooms, as has been demonstrated by Ulva blooms in the Yellow Sea due to Pyropia cultivation. However, all papers reporting the risk of macroalgal blooms resulting from seaweed cultivation were related to the regional events that have occurred in the Yellow Sea, and to date we could find no evidence of macroalgal blooms occurring due to seaweed cultivation in Europe. Additional negative impacts identified in the reviewed papers included introduced species, disease or pest outbreaks, biofouling, light attenuation, conflict with other users (e.g. wind farms), increased halocarbon production (in tropical regions), flow reduction due to seaweed farms, changes in organic matter in surface sediments, and decreased benthic diversity. Finally, negative impacts that were placed in the "other" category were mentioned less than three times among the reviewed papers or they could not be assigned to a meaningful category. These included the following: poor acceptance of seaweed aquaculture among stakeholders due to bad experiences in other aquaculture sectors, creation of urban artificial shorelines, provision of jobs, but at the expense of farmers' health, competition with microalgae, ammonia release from seaweeds, competition with microalgae, and sediment deposition in beach areas.

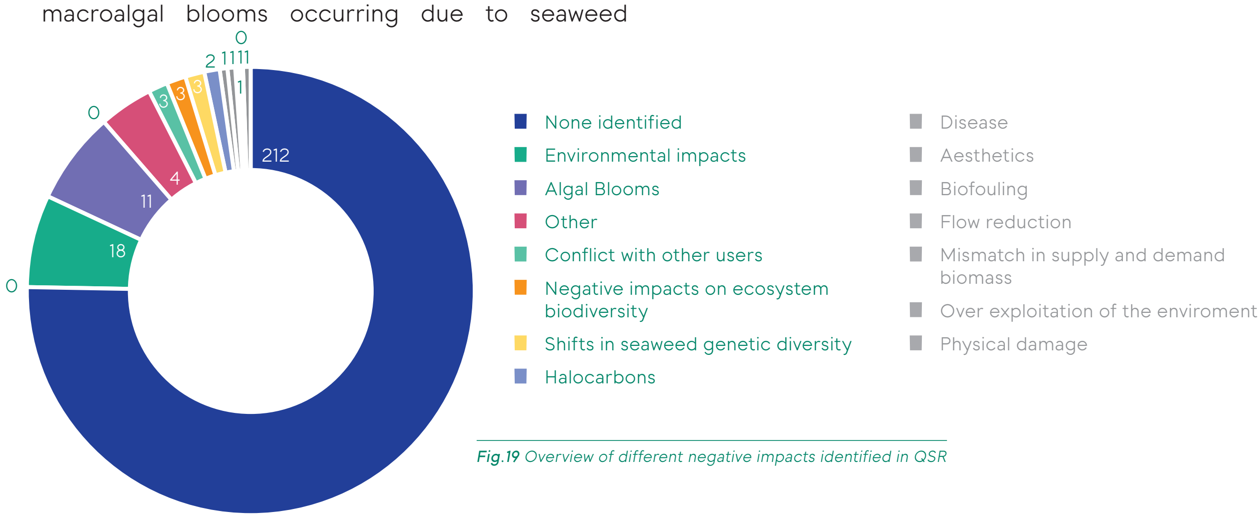


Fig.19 Overview of different negative impacts identified in QSR

5.2.6 Knowledge Gaps

From the 280 studies analysed, 172 (61%) of the studies identified knowledge gaps. These gaps were classified into seven categories relating to seaweed culture using the PESTEL framework. In addition, a further category, not applicable ('NA'), was included, when no knowledge gaps were highlighted by the study (128 papers, equivalent to 46%) (Fig. 20). The seven categories were further divided into 32 sub-categories and a full description of the knowledge gaps identified under each group/ sub-group can be found in Annex 5.

The main categories for knowledge gaps (other than NA) with the highest percentage were identified as Technical (24.5%) and Environmental (19%), followed by the social, economic and legal categories (Fig. 20). It should be recognized that the low number of knowledge gaps in the social category might be a reflection of the lack of studies on cultural ecosystem services provided by seaweed cultivation (see Fig. 13).

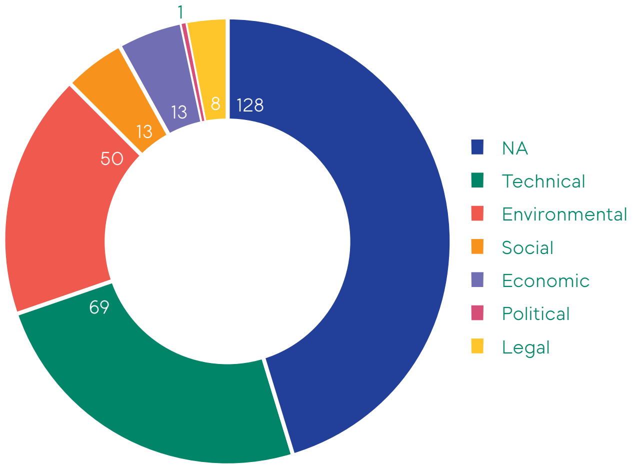


Fig. 20 Overview of the key knowledge gaps identified through the Quick Scoping Review and classified into the eight main categories (n=280)

Technical knowledge gaps. Within the technical knowledge gaps, the production sub-category was by far the most dominant (47%), including how to accurately predict optimal farm size, production biomass and associated growth rates, particularly when using new farming methods (e.g., rafts) and/ or offshore locations (Fig. 21). In addition, technical knowledge was highlighted as lacking in seaweed attachment mechanisms, the influence of depth, light exposure and aeration / water movement, in the nursery and on-growing phases, on growth rates and factors that influence/ limit nitrate and phosphate uptake at farm, regional and global scales. Also, the potential to monitor carrageenan content, disease outbreaks using satellites and biofiltration rates was also identified as a knowledge gap.

The second most cited technical knowledge gap was identified as technology (23.5%), in which knowledge on the effectiveness of new innovative techniques at large scale, such as land/sea based IMTA systems, new seeding techniques, new species, floating longlines was identified. Knowledge gaps were also highlighted in energy saving processing (e.g., by-product extraction), effectiveness of depth-cycling to increase nutrient availability and prevent thermal stress and bioprospecting. The third most commonly cited knowledge gap was technology - unclassified (10%), in which the specific nature of the knowledge gap was not described. Further information on the other technical sub-categories can be found in Fig. 20 and Annex 5.

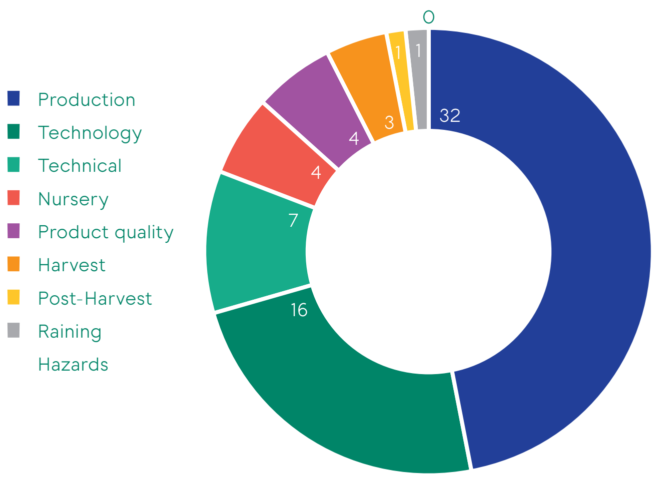


Fig.21 Overview of the 'Technical' sub-categories of knowledge gaps identified through the Quick Scoping Review (n=68)

Environmental knowledge gaps. Within the environmental knowledge gaps, wider ecosystem effects were the most dominant sub-category (29 %), comprising the gaps in knowledge of how upscaling seaweed farms would affect adjacent coral reefs, phytoplankton and microbial communities, seagrass beds and seaweed populations, fish assemblages, fish farms, water quality, particularly in light of the creation of novel habitats. The lack of knowledge on the effect of stocking density on the wider ecosystem and the persistence of existing ecosystem services around the cultivation site, once in operation, were also highlighted (Fig. 22). The second most cited environmental knowledge gap was identified as nuisance species/ disease (25.5%), in which how to deal with encrusting or epiphytic organisms, which can affect biomass, quality and/or cultivation process were highlighted.

A lack of knowledge on seaweed diseases, biofouling, harmful algal bloom formation and their mitigation measures was also identified. The third most commonly cited knowledge gap was emissions and absorption (18 %), in terms of absorption of CO2, uptake of nutrients and release of dissolved and particulate nitrates and phosphates from large-scale seaweed farms. In addition, lack of knowledge on what the benthic and carbon footprint of these large farms would be and how this would vary dependent on the species that was being cultivated was highlighted. Further information on the other sub-categories can be found in Fig. 22 and Annex 5.

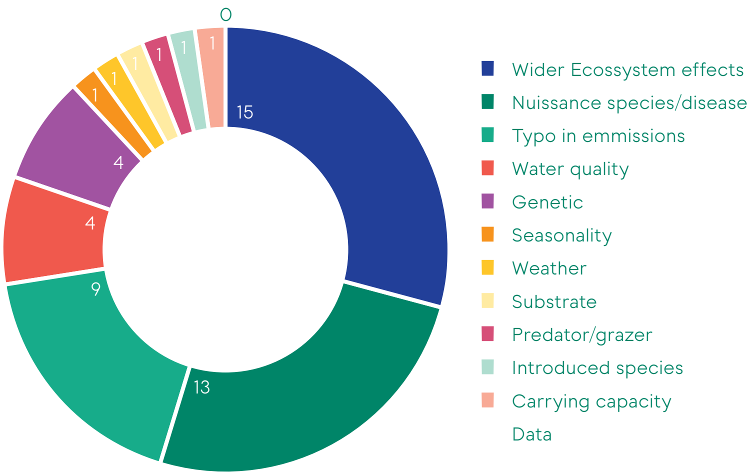


Fig.22 Overview of the 'Environmental' sub-categories of knowledge gaps identified through the Quick Scoping Review (n=51)

Diverse knowledge gaps were identified at all scales of the macroalgae cultivation process, from nurseries to scale-up production and processing.

DISCUSSION

6 Discussion

6.1 Reflection on the Delphi methodology

Assessing the replies to the first and second round of the Delphi questionnaire, the following observations are made. In reply to the questions, various respondents provided a few key words, not elaborating further. Given the expertise of the working group, these answers have been processed for further analysis. However, cautious of over interpretation, the answers were not reformulated. This shows, for example, in the section on knowledge gaps where answers provided were generally not formulated as a gap. The 22 answers obtained for the first round were considered satisfactory, even though they represented less than 20% of requests sent. The limited number of replies to the second round of the Delphi questionnaire is considered much more limited in terms of opportunities for analysis.

In general, we received a low number of expert opinions from the questionnaire used in the Delphi process. Most of the responses were from academia and research. Very few experts were from industry, NGOs, professional and international organisations. Therefore, there may be considerable bias in the responses, but such bias is always a risk with the Delphi process, and therefore the QSR was done in parallel to accommodate such bias. Additionally, few experts focused on marketing and sales, macroalgae genetic characterization and breeding, education, management and conservation of brown algae, kelp forest studies/seaweed diversity/phylogeography, and macroalgae diversity/macroalgae genetics/ macroalgae horticulture. These observations suggest that in order to obtain a broader response, the different stakeholders may need to be engaged in different ways. Considering that it can be difficult to define ES and assess which of these are realistically provided by seaweed cultivation it is possible that some of the participants may have not been familiar with the concept of ES and how to define them. In the future, it will be necessary to take a more interdisciplinary and multi-stakeholder approach in order to reach a broader audience. Additionally, for future studies it would be important to increase the number of invitations and/or try to contact the potential respondents first, making sure they commit to be involved throughout the entire process.

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***Kappaphycus**, cultivated in the Philippines.*

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***Handful** of seaweeds -Ulva fenestrata and Ceramium virgatum from the North Sea.*

6.2 Quality of the QSR compiled data set

Findings of the QSR strongly reflected that most of the studies were focused on pilot or small-scale farms, near-shore seaweed cultivation, mainly conducted in Asian and European countries. This underlies the novelty of seaweed farms in European waters, with no or limited examples of larger scale cultivation compared to Asia where seaweed farms already operate at medium-large scales. It should be pointed out that there was a mismatch between the high scientific interest in seaweed cultivation in Europe (24% of scientific publications, ranked 2nd after Asia according to our QSR) and the low volume of seaweed production in Europe (<0.1% of total seaweed production; FAO 2020; Araujo et al. 2021; Table 10), compared to Asian production. The small size of seaweed farms (pilot and small farms 38% of studies vs. medium and large farms 26%) considered in most of the scientific studies might lead to some bias that needs to be considered when interpreting the results and identifying knowledge gaps, as some processes, services and disservices can be size dependent (Campbell et al., 2019).

Table 10 Information defining the scientific production in the different areas, such as the ratio between small (i.e. pilot and small) and large (i.e. medium and large) farms studies, the ratio between the production of seaweeds in 2016 and the number of eligible articles published from January 2000 to June 2021, the percentage of modelling studies, the number of eligible identified and the seaweed aquaculture production in 2016 (sources: FAO, 2020 and Araujo et al., 2021). ND indicates no data; blue is the minimum and yellow is the maximum for each category.

	SMALL/LARGE	PRODUCTION/ ARTICLES	MODELLING ARTICLES	N-ARTICLES	PRODUCTION 2016
Africa	2.00	7.14	0.00	18	128.5
Asia	0.54	269.74	6.76	74	19961
Europe	2.36	0.01	26.56	64	0.6
Latin America	5.33	0.57	11.54	26	14.8
North America	3.50	ND	18.18	12	ND
Oceania	2.10	23.57	5.17	58	1366.9

While assessing the papers, the expert working group identified weaknesses in experimental design or approach, analysis, and scale (both spatial and temporal), which affected about 12% of the reviewed literature.

The provided data set of QSR revealed a high diversity of seaweed taxa (about 77 species) approached in cultivation, whereas only few species, mainly belonging to the kelps, were the subject of intensive study and thus baseline of the present QSR. This might bias the outcome and conclusions in some way, considering that a variety of additional species/genera are identified and are currently tested for implementation in seaweed aquaculture. Also the approach of polyculture, e.g. IMTA combining the cultivation of different taxa at the same location, could alter the received findings in future.

Although European studies dealt with 17 different species, most of the studies were focused on kelps (*Saccharina latissima, Laminaria digitata and Alaria esculenta*) due to their present commercial value.

It must be also noted that there will probably be a time lag between the ongoing research and the results already published, as the former may not be represented in the QSR. On the other hand, as a result of the economical profitability of new applications and the patents limitations, these studies may be underrepresented in the published scientific literature.

6.3 Ecosystem services provided by seaweed cultivation

While 85% of the ecosystem services provided by seaweed cultivation based on the Delphi process fell into the "Regulating and Maintenance" category, the QSR results showed 45% of studies provided evidence of "Regulating and Maintenance" services and 48.5% provided evidence of "Provisioning" services. However, in the second round of the Delphi process, when participants were asked to rank the ecosystem services in order of importance, provisioning services (e.g. food and hydrocolloids) were ranked as the most important ecosystem services.

Although the ranking of the experts was not necessarily reflected in the literature, both methods identified the following top six ecosystem services provided by seaweed cultivation:

1. Provisioning food,
2. Provisioning hydrocolloids and feed,
3. Regulating water quality,
4. Provisioning habitats,
5. Provisioning of nurseries and
6. Regulating climate.

6.4 Knowledge Gaps inhibiting scale-up and delivery of ecosystem services by macroalgae cultivation

Diverse 'Technological' knowledge gaps were identified by both methods at all scales of the macroalgae cultivation process, from nurseries (e.g. strain selection, attachment effectiveness; Kerrison et al., 2016) to production and scale-up (e.g. biofiltration rates, ensuring consistent biomass/ product quality, effectiveness of new technologies at scale) to processing (e.g. how to improve energy efficiency). This focus on technological knowledge gaps may result from the fact that the majority of the respondents to the Delphi questionnaire were from Europe, who generally may have less experience with seaweed cultivation at large scales.

The second most common category of knowledge gaps according to the Delphi process was 'Economic' (e.g. detailed market information/data, valorization of ecosystem services, carbon credits, and lack of successful business cases). In contrast, the second most common knowledge gap category identified during the QSR was 'Environmental' (e.g. wider ecosystem effects, nuisance species/disease, and emissions/absorption). The discrepancy in most commonly identified knowledge gaps between the two methods may be due to the fact that the economic knowledge gaps in the seaweed industry are often not reflected or reported in the scientific literature (e.g. business cases, yield costs may not be shared to protect industrial interests).

Based on suggestions from the expert respondents in the Delphi process, there is a clear need for a European-wide strategy for reducing risk for seaweed producers, providing clear standards and guidelines for obtaining permits, and providing financial support to improve technological innovation that will ensure consistent quality. Furthermore, it should be noted that seaweed biomass has generally a low gross monetary value and the labour conditions associated with seaweed aquaculture to be profitable are in many cases not acceptable for the European standards and legislation. In this sense, it would be critical for the development of European seaweed aquaculture to identify high-value products and technological innovations to reduce costs in terms of work hours.

An additional knowledge gap that was identified when analysing the ES provided by different taxa is that it needs to be determined if polyculture of macroalgae (using several algal species) will provide more ES than monoculture at a large scale.

Despite the fact that many experts ranked climate regulation as an ecosystem service provided by macroalgae cultivation, strong evidence of this service is still lacking in the literature and there are still many open questions regarding if and how macroalgae cultivation at a large scale can sequester carbon, and the carbon balance along the production chain.

6.5. Main constraints limiting scale-up of macroalgae cultivation

The observed discrepancies between the constraints identified during the Delphi process (mainly Political/ Legal, Technological, Economic) and the QSR (mainly Environmental and Technological), might be partly explained, as mentioned above for the knowledge gaps, by the novel/developing status of the seaweed aquaculture in European waters thus it shows a prioritised need for developing a required political/ legal framework and establishing appropriate farming technologies. In addition, the high cost of labour in Europe compared to other countries where seaweed cultivation is well established requires a different approach, for example by incorporating technological advances that automate and, hence, reduce the cost of, seaweed production. Concerning the environmental constraints, the occurrence of nuisance species was the most dominant factor. This constraint is also reflected in the high number of papers that reported the occurrence of Ulva spp. blooms resulting from Pyropia sp. cultivation in the Yellow Sea as a negative impact of seaweed cultivation. Additional environmental constraints included site specific inter-environmental dynamics (e.g. seasonal appearance of nuisance species, alterations in water quality, pollution, biofouling; Rolin et al., 2017, 138, 275). Depending on regional water quality standards, some areas of Europe may be unsuitable for seaweed cultivation due to pollution. There are also seasonal restrictions in Europe that are not necessarily relevant in other regions where large-scale seaweed cultivation is already well established and can be carried out all year round. These seasonal restrictions limit the production period of some species, the ecosystem services that they can provide are not always present and hence the profit obtained. This reflects on the one hand the need for further investigation to understand the different abiotic and biotic factors involved and also underlines the required flexibility concerning site specific adaptations for establishing a working seaweed farm. In this context, accompanying monitoring could be a way to provide further support for the planning of new and further implementation of already established sites.

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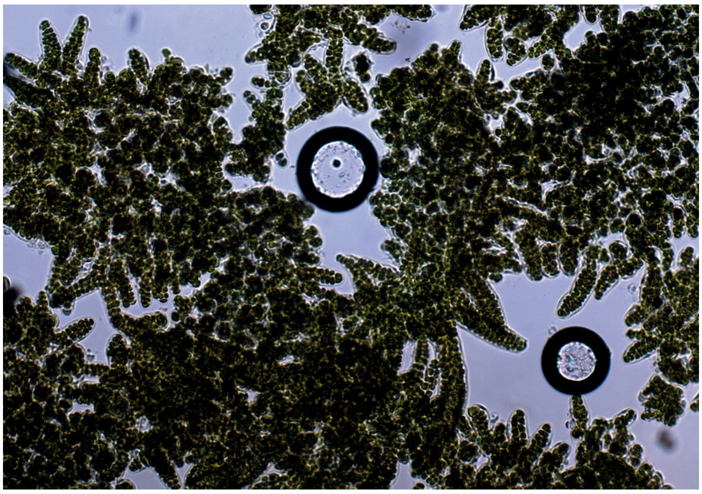
Chondracanthus teedei *cultivated in Cadiz Bay (Southern Spain).*

6.6 Potential negative impacts or trade-offs of scaling-up macroalgal cultivation

Unknown environmental impacts to deep sea, benthic and pelagic ecosystems was one of the most commonly identified potential negative impacts of macroalgae cultivation both among the expert responses and the reviewed articles. This point is especially relevant if the goal is climate change mitigation due to the scale required and the large amount of biomass that could be entered in the deep ocean.

In addition, conflicts with other users, shifts in seaweed genetic diversity, negative impacts on ecosystem biodiversity and reductions in water flow were identified as potential negative impacts of scaling-up macroalgae cultivation by both methods. Nevertheless, most negative impacts were identified as potential or unknown and few studies provided direct evidence of negative impacts of seaweed cultivation, except in cases of poor management practice (e.g., cloning, uncontrolled transport of strains between sites/regions). This underlines again the need of further, accompanying multidisciplinary approaches and transparency, considering site specific conditions and need for comparative examples. In this context, the built and interlinking of interdisciplinary seaweed farmer- research networks, providing information and access to developing methodologies, as well as information on successful case studies, would provide a sustainable way to support the further developments in the seaweed cultivation sector.



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***Germlings** of Ulva fenestrata.*

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***Seeded rope** with Sacarina latissima.*

CONCLUSIONS

7 Conclusions

The present study highlights that seaweed cultivation can provide many ES to humanity. However, one of the main issues recognized during the presented study was the understanding of ES themselves by the different stakeholders. There was often no clear evidence of ES provided found in the literature and also some aspects, like cultural impact etc. were missing in the responses to the questionnaires during the Delphi process. At present, there seems to be not only uncertainties in definitions, but also a lack in understanding of the potential importance of the defined ES for further development of the seaweed cultivation industry. Clear definitions of ecosystem services are required to be communicated and agreed within and among stakeholders involved in seaweed cultivation to facilitate further valorisation and analysis of the ecological and economical footprint of large-scale seaweed production. In this context the presented approach combining CICES v.5 and PESTEL analysis provided a valuable tool to define and categorise ES in the seaweed cultivation sector.

Most of the studies addressing ES provided by seaweed aquaculture were not comprehensive and overall focused on a few services (e.g., biomass provision, nutrient removal, biological regulation or blue carbon), while others (e.g., cultural services) were poorly represented. However, the number of studies reporting a certain service (e.g., regulating water quality) is not necessarily a direct reflection of the importance or value of that particular service. There is clearly a bias in the literature on studies investigating bioremediation of seaweeds, but very few studies provide valorisation of this service. In contrast, cultural services, such as improving social welfare or gender equality, are poorly represented in the literature. That is not to say that such cultural services are less valuable than water quality regulation, but such a direct comparison of the value of different ecosystem services provided by seaweed cultivation is still lacking, as it was outside the scope of this study.

Relevant knowledge gaps have been identified in most of the PESTEL categories, particularly in technological, economical/social and environmental issues. Technological improvements, and the identification of valuable products and species were the main actions suggested by experts during the Delphi process to harness the potential of seaweed aquaculture in Europe. The lack of a clear regulation about biomass quality standards (e.g., content of heavy metals, contamination by bacteria and other compounds of potential concern for human health) and guidelines to obtain the necessary permits is another problem usually highlighted by seaweed farmers constraining the development of seaweed cultivation. In addition, only limited information about the potential consequences of climate change for macroalgae cultivation has been reported so far. Even in these cases, the scale of aquaculture facilities was generally limited and currently there is an important uncertainty about the upscaling of the activity. It should be noted that climate and environmental conditions, and the viability of seaweed aquaculture and its provision of ES could be interrelated when seaweed aquaculture is developed at a large scale. For instance, in some regions where seaweed aquaculture has been developed at large scale, the fertilisation of coastal waters, namely from river inputs (258), has been necessary to increase or maintain the production of seaweeds. This raises the need to control the nutrient fluxes connected with large-scale seaweed cultivation. Although there is a relevant number of studies dealing with nutrient (including carbon) removal and bioremediation (e.g. 68, 106), most of the studies did not consider the entire life cycle, and overall did not discuss the scale of the facilities or cultures necessary for an effective remediation.

Some of the ES will be delivered only at large scale cultivation (e.g., carbon sequestration, climate regulation), but even in the existing few cases there is little evidence to support this (e.g. 258, Aldrige et al. 2012, Campbell et al. 2019). At this scale of operations there could be multiple associated unknown side effects, which need to be further investigated (e.g., pumping deep waters to fertilise seaweed, which not only bring to the surface required growth-limiting nutrients, but also already sequestered carbon; e.g. 56, 57).

All the above conclusions are summarized in a conceptual model (Fig. 23), highlighting constraints, knowledge gaps and open questions around seaweed farming, for each PESTEL category. The figure also shows the potential ecosystem services and disservices of seaweed aquaculture identified in the literature review (Fig. 23).

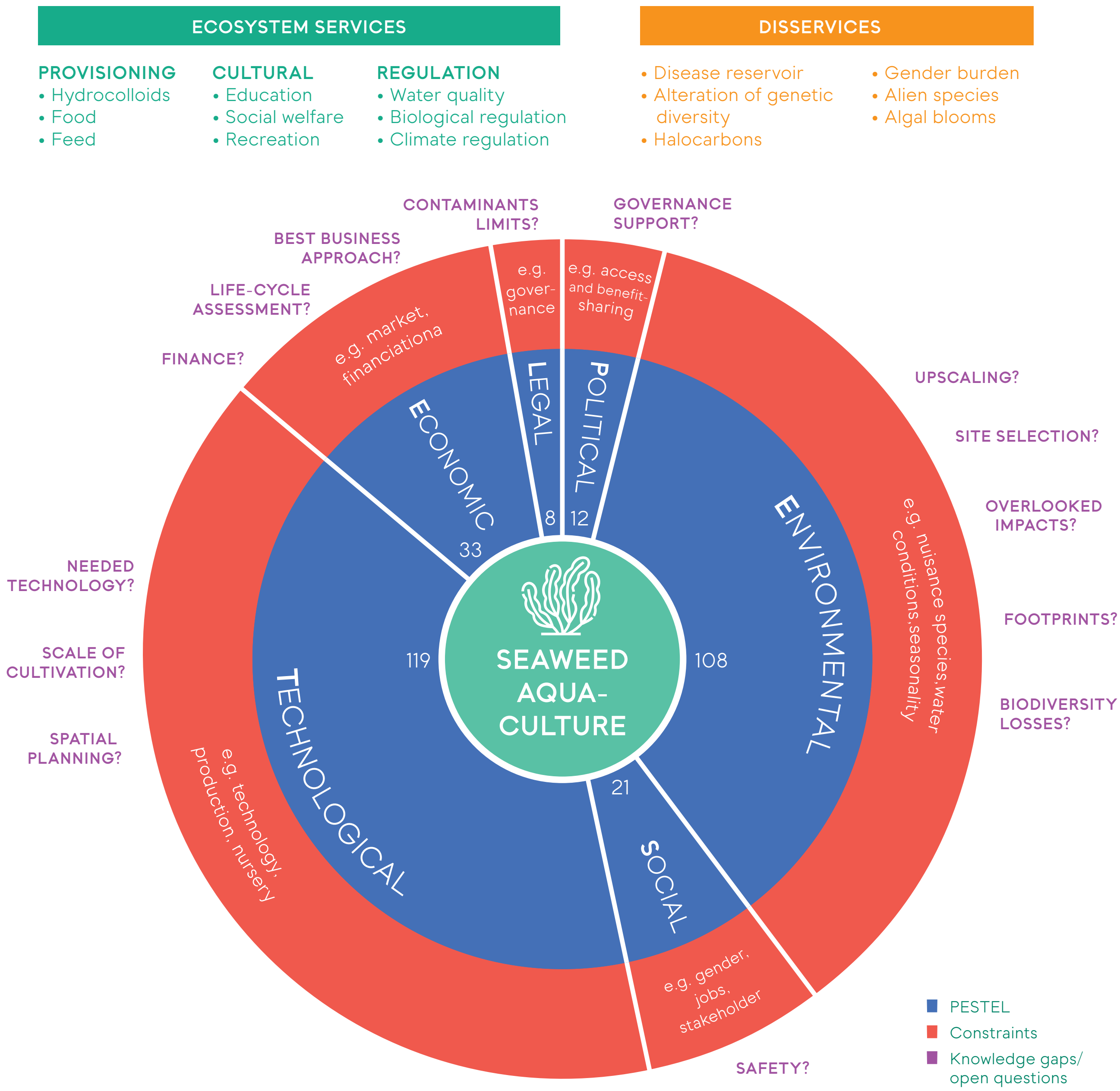

Fig 23. Conceptual model summarising constraints, knowledge gaps and existing open questions (for each PESTEL category) of seaweed aquaculture, as well as potential related ecosystem services and disservices identified in this study. Sizes of PESTELs correspond to their importance, based on the total contribution of constraints and knowledge gaps from the QSR.

7.1 Outlook

Based on the responses to the questionnaire and the analysis of the scientific literature through the QSR, we provide below a summary of the major knowledge gap topics that were identified in this study and related questions, which, once answered, will help guide the further development and expansion of seaweed cultivation in Europe (Table 11). In some cases, we provide solutions for how to answer the questions related to the knowledge gaps based on the results of this study.

***Table 11** Overview of identified knowledge gaps and corresponding guiding questions*

KNOWLEDGE GAP	OPEN QUESTIONS
Site selection	■ Which environmental parameters define a suitable site for the implementation of a sustainable seaweed farm?
Scale of cultivation	■ How does the scale of seaweed cultivation affect the ecosystem services provided? ■ At what scale does seaweed cultivation provide the most ecosystem services and the most economic benefit? Do these scales match? ■ How can the carrying capacity for seaweed cultivation (or optimal farm size) in a particular area/water body be quantified?
Technology	■ How can we improve the technological advancement of macroalgae production? ■ How can consistent biomass/product quality be ensured? • Clear standards and guidelines for obtaining permits • Reducing risks to seaweed farmers • Financial support for technological innovation • Identification of high value products ■ How can seaweed production and processing become more energy efficient?
Economics	■ What is the best business approach for different scales of seaweed cultivation in Europe?
Environment	■ What are the environmental and carbon footprints of large-scale seaweed farms, and does this depend on the species cultivated? ■ How can losses due to nuisance species/disease/pests be minimized?

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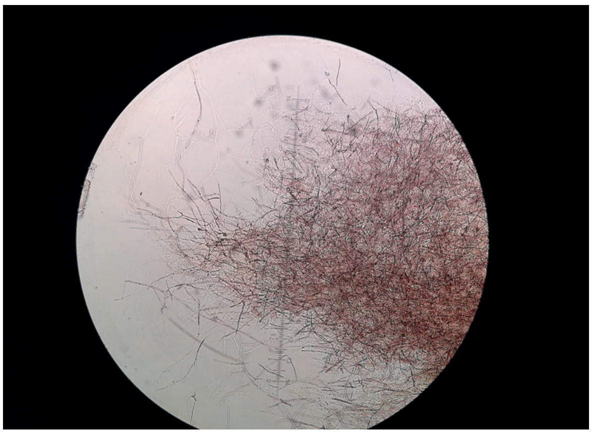
***Young sporophytes** of Sacarina latissima.*



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***Conchocelis phase** of Neopyropia leucosticta.*

8. Bibliography

References

Aldridge, J., van de Molen, J., & Forster, R. (2012). Wider Ecological Implications of Macroalgae Cultivation. London: The Crown Estate, 95 pp.

Alleway, H.K., Gillies, C.L, Bishop, M.J., Gentry, R.R., Theuerkauf, S.J., & Jones, R, (2019) The ecosystem services of marine aquaculture: Valuing benefits to people and nature. BioScience, 69: 59-68. doi.org/10.1093/biosci/biy137.

Araujo, R., Vázquez-Calderón, F., Sánchez-López, J., Costa-Azevedo, I., Bruhn, A., Fluch, S., García-Tasende, M., Ghaderiardakani, F., Ilmjärv, T., Laurans, M., Mac Monagail, M., Mangini, S., Peteiro, C., Rebours, c., Stefanssons, T., Ullmann, J. (2021) Current Status of the algae Production Industry in europe: An Emerging Sector of the Blue Bioeconomy. Frontiers in Marine Science 7:626389. https://doi.org/10.3389/fmars.2020.626389

Bak, U.G., Gregersen, O., & Infante, J. (2020). Technical challenges for offshore cultivation of kelp species: lessons learned and future directions. Botanica Marina 160: 341-353. https://doi.org/10.1515/bot-2019-0005

Basset, A., Barbone, E., Elliott, M., Li, B-L., Jorgensen, S.E., Lucena-Moya, P., Pardo, I., & Mouillot, D (2013). A unifying approach to understanding transitional waters: Fundamental properties emerging from ecotone ecosystems. Estuarine, Coastal and Shelf Science, 132: 5-16. https://doi.org/10.1016/j.ecss.2012.04.012

Basu, R (2004) Tools for Analysis - PESTLE Analysis. In: Implementing Quality: A Practical Guide to Tools and Techniques, First edition., London, Thomson Learning, pp. 98-100.

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

Collins, C., Richards, R., Reeder, A. I., & Gray, A. R. (2015). Food for thought: edible gardens in New Zealand primary and secondary schools. Health Promotion Journal of Australia, 26(1), 70-73. https://doi.org/10.1071/HE14082.

Dalkey, N., & Helmer, O. (1963). An experimental application of the Delphi Method to the use of Experts. Management Science, 9(3), 458-467. https://doi.org/10.1287/mnsc.9.3.458

Duarte, C.M., Bruhn, A., & Krause-Jensen, D. A. (2021). Seaweed aquaculture imperative to meet global sustainability targets. Nature Sustainability. https://doi.org/10.1038/s41893-021-00773-9.

Eklipse Expert Working Group Macroalgae (2021). Method Protocol, August 2021.

FAO (2020). The State of World Fisheries and Aquaculture 2020. Sustainability in action. Rome. https://doi.org/10.4060/ca9229en

Guiry, M.D. & Guiry, G.M. (2022). AlgaeBase. World-wide electronic publication, National University of Ireland, Galway. https://www.algaebase.org; searched on 30th January 2022.

Haines-Young, R., & Potschin-Young, M. (2018). Revision of the Common International Classification for Ecosystem Services (CICES V5.1): A Policy Brief. One Ecosystem, 3, e27108.

Hughes, A. (2021). Defining nature-based solutions within the Blue Economy: The example of aquaculture. Frontiers in Marine Science 8:711443. https://doi.org/10.3389/fmars.2021.711443

Kerrison, P.D., Stanley, M.S., Kelly, M., MacLeod, A., Black, K.D., Hughes, A.D. (2016) Optimising the settlement and hatchery culture of Saccharina latissima (Phaeophyta) by manipulation of growth medium and substrate surface condition. Journal of Applied Phycology 28: 1181–1191. https://doi.org/10.1007/s10811-015-0621-6.

Krause-Jensen, D., Lavery, P., Serrano, O., Marbà, N., Masque, P., & Duarte, C.M. (2018) Sequestration of macroalgal carbon: the elephant in the Blue Carbon room. Biology Letters 14: 20180236. https://doi.org/10.1098/rsbl.2018.0236.

Mukherjee, N., Hugé, J., Sutherland, W. J., McNeill, J., Van Opstal, M., Dahdouh-Guebas, F., & Koedam, N. (2015). The Delphi technique in ecology and biological conservation: applications and guidelines. Methods in Ecology and Evolution, 6(9), 1097-1109. https://doi.org/10.1111/2041-210X.12387.

Rolin, C., Inkster, R., Laing, J., & McEvoy L. (2017). Regrowth and biofouling in two species of cultivated kelp in the Shetland Islands, UK. Journal of Applied Phycology 29: 2351–2361. https://doi.org/10.1007/s10811-017-1092-8.

U.N. (2015). Global Sustainable Development Report, 198 pp. Retrieved from: https://sustainabledevelopment.un.org/globalsdreport/2015.

References forming the base of the QSR

1. Abhilash, K. R., Sankar, R., Purvaja, R., Deepak, S. V., Sreeraj, C. R., Krishnan, P., Sekar, V., Biswas, A. K., Kumarapandiyan, G., & Ramesh, R. (2019). Impact of long-term seaweed farming on water quality: a case study from Palk Bay, India. Journal of Coastal Conservation, 23(2), 485–499. https://doi.org/10.1007/s11852-018-00678-4

2. Abreu, M. H., Pereira, R., Yarish, C., Buschmann, A. H., & Sousa-Pinto, I. (2011). IMTA with Gracilaria vermiculophylla: Productivity and nutrient removal performance of the seaweed in a land-based pilot scale system. Aquaculture (Amsterdam, Netherlands), 312(1–4), 77–87. https://doi.org/10.1016/j.aquaculture.2010.12.036

3. Malik, A., Mertz, O., & Fensholt, R. (2017). Mangrove forest decline: consequences for livelihoods and environment in South Sulawesi. Regional Environmental Change, 17(1), 157-169. https://doi.org/10.1007/s10113-016-0989-0

4. Aeni, O. N.; Aslan, L. O. M.; Iba, W.; Patadjai, A. B.; Rahim, M. & Balubi, M.(2019) Effect of different seedling sources on growth and carrageenan yield of seaweed Kappaphycus alvarezii cultivated in Marobo Waters, Muna Regency, Southeast (Se) Sulawesi, Indonesia. IOP Conf. Ser. Earth Environ. Sci. https://doi.org/10.1088/1755-1315/382/1/012015/meta

5. Afiah, R. N., Supartono, W., & Suwondo, E. (2019). Potential of heavy metal contamination in cultivated red seaweed (Gracilaria sp. and Eucheuma cottonii) from coastal area of Java, Indonesia. IOP Conference Series. Earth and Environmental Science, 365(1), 012024. https://doi.org/10.1088/1755-1315/365/1/012024

6. Aitken, D., Bulboa, C., Godoy-Faundez, A., Turrion-Gomez, J. L., & Antizar-Ladislao, B. (2014). Life cycle assessment of macroalgae cultivation and processing for biofuel production. Journal of Cleaner Production, 75, 45–56. https://doi.org/10.1016/j.jclepro.2014.03.080

7. Ajith, S., Rojith, G., Zacharia, P. U., Nikki, R., Sajna, V. H., Liya, V. B., & Grinson, G. (2019). Production, characterization and observation of higher carbon in Sargassum wightii biochar from Indian coastal waters. Journal of Coastal Research, 86(sp1), 193. https://doi.org/10.2112/si86-029.1

8. Aldridge, J. N., Mooney, K., Dabrowski, T., & Capuzzo, E. (2021). Modelling effects of seaweed aquaculture on phytoplankton and mussel production. Application to Strangford Lough (Northern Ireland). Aquaculture (Amsterdam, Netherlands), 536(736400), 736400. https://doi.org/10.1016/j.aquaculture.2021.736400

9. Andrade, H. M. M. de Q., Rosa, L. P., Souza, F. E. S. de, Silva, N. F. da, Cabral, M. C., & Teixeira, D. I. A. (2020). Seaweed production potential in the Brazilian northeast: A study on the Eastern coast of the state of Rio Grande do Norte, RN, Brazil. Sustainability, 12(3), 780. https://doi.org/10.3390/su12030780

10. Ashkenazi, D. Y., Israel, A., & Abelson, A. (2019). A novel two-stage seaweed integrated multi-trophic aquaculture. Reviews in Aquaculture, 11(1), 246–262. https://doi.org/10.1111/raq.12238

11. Aslan, L. O. M., Iba, W., Bolu, L. O. R., Ingram, B. A., Gooley, G. J., & de Silva, S. S. (2015). Mariculture in SE Sulawesi, Indonesia: Culture practices and the socio economic aspects of the major commodities. Ocean & Coastal Management, 116, 44–57. https://doi.org/10.1016/j.ocecoaman.2015.06.028

12, Azevedo, I. C., Duarte, P. M., Marinho, G. S., Neumann, F., & Sousa-Pinto, I. (2019). Growth of Saccharina latissima (Laminariales, Phaeophyceae) cultivated offshore under exposed conditions. Phycologia, 58(5), 504–515. https://doi.org/10.1080/00318884.2019.1625610

13. Bach, L. T., Tamsitt, V., Gower, J., Hurd, C. L., Raven, J. A., & Boyd, P. W. (2021). Testing the climate intervention potential of ocean afforestation using the Great Atlantic Sargassum Belt. Nature Communications, 12(1). https://doi.org/10.1038/s41467-021-22837-2

14. Badis, Y., Klochkova, T. A., Strittmatter, M., Garvetto, A., Murúa, P., Sanderson, J. C., Kim, G. H., & Gachon, C. M. M. (2019). Novel species of the oomycete Olpidiopsis potentially threaten European red algal cultivation. Journal of Applied Phycology, 31(2), 1239–1250. https://doi.org/10.1007/s10811-018-1641-9

15. Badraeni R., Syamsuddin, H., & Samawi, F. (2020). Weeds, epiphytes and ice-ice disease on green-strained Kappaphycus alvarezii (Doty) in takalar waters, South Sulawesi in different seasons and locations of cultivation. Plant Archives, 20 (2). 2327-2332

16. Bak, U. G., Mols-Mortensen, A., & Gregersen, O. (2018). Production method and cost of commercial-scale offshore cultivation of kelp in the Faroe Islands using multiple partial harvesting. Algal Research, 33, 36–47.
https://doi.org/10.1016/j.algal.2018.05.001

17. Bambaranda, B.V.A.S.M., Tsusaka, T. W., Chirapart, A., Salin, K. R., & Sasaki, N. (2019). Capacity of Caulerpa lentillifera in the removal of fish culture effluent in a recirculating aquaculture system. Processes (Basel, Switzerland), 7(7), 440.
https://doi.org/10.3390/pr7070440

18. Barberi, O. N., Byron, C. J., Burkholder, K. M., St. Gelais, A. T., & Williams, A. K. (2020). Assessment of bacterial pathogens on edible macroalgae in coastal waters. Journal of Applied Phycology, 32(1), 683–696.
https://doi.org/10.1007/s10811-019-01993-5

19. Basaure, H., Macchiavello, J., Sepúlveda, C., Sáez, F., Yañez, D., Vega, L., & Marín, C. (2021). Sea bottom culture of Chondracanthus chamissoi (Rhodophyta: Gigartinales) by vegetative propagation at Puerto Aldea, Tongoy Bay (Northern Chile). Aquaculture Research, 52(5), 2025–2035.
https://doi.org/10.1111/are.15051

20. Beltran-Gutierrez, M., Ferse, S. C. A., Kunzmann, A., Stead, S. M., Msuya, F. E., Hoffmeister, T. S., & Slater, M. J. (2016). Co-culture of sea cucumber Holothuria scabra and red seaweed Kappaphycus striatum. Aquaculture Research, 47(5), 1549–1559.
https://doi.org/10.1111/are.12615

21. Ben-Ari, T., Neori, A., Ben-Ezra, D., Shauli, L., Odintsov, V., & Shpigel, M. (2014). Management of Ulva lactuca as a biofilter of mariculture effluents in IMTA system. Aquaculture (Amsterdam, Netherlands), 434, 493–498.
https://doi.org/10.1016/j.aquaculture.2014.08.034

22. Bermejo, R., Cara, C. L., Macías, M., Sánchez-García, J., & Hernández, I. (2020). Growth rates of Gracilariopsis longissima, Gracilaria bursa-pastoris and Chondracanthus teedei (Rhodophyta) cultured in ropes: implication for N biomitigation in Cadiz Bay (Southern Spain). Journal of Applied Phycology, 32(3), 1879–1891.
https://doi.org/10.1007/s10811-020-02090-8

23. Bermejo, R., Macías, M., Cara, C. L., Sánchez-García, J., & Hernández, I. (2019). Culture of Chondracanthus teedei and Gracilariopsis longissima in a traditional salina from southern Spain. Journal of Applied Phycology, 31(1), 561–573.
https://doi.org/10.1007/s10811-018-1516-0

24. Billing, S.L., Rostan, J., Tett, P., & Macleod, A. (2021). Is social license to operate relevant for seaweed cultivation in Europe? Aquaculture (Amsterdam, Netherlands), 534(736203), 736203.
https://doi.org/10.1016/j.aquaculture.2020.736203

25. Bindu, M. S. (2011). Empowerment of coastal communities in cultivation and processing of Kappaphycus alvarezii—a case study at Vizhinjam village, Kerala, India. Journal of Applied Phycology, 23(2), 157–163.
https://doi.org/10.1007/s10811-010-9597-4

26. Biswas, G., Kumar, P., Kailasam, M., Ghoshal, T. K., Bera, A., & Vijayan, K. K. (2019). Application of integrated multi trophic aquaculture (IMTA) concept in brackishwater ecosystem: The first exploratory trial in the sundarban, India. Journal of Coastal Research, 86(sp1), 49.
https://doi.org/10.2112/si86-007.1

27. Bolton, J. J., Robertson-Andersson, D. V., Shuuluka, D., & Kandjengo, L. (2009). Growing Ulva (Chlorophyta) in integrated systems as a commercial crop for abalone feed in South Africa: a SWOT analysis. Journal of Applied Phycology, 21(5), 575–583.
https://doi.org/10.1007/s10811-008-9385-6

28. Bouwman, A. F., Pawłowski, M., Liu, C., Beusen, A. H. W., Shumway, S. E., Glibert, P. M., & Overbeek, C. C. (2011). Global hindcasts and future projections of coastal nitrogen and phosphorus loads due to shellfish and seaweed aquaculture. Reviews in Fisheries Science, 19(4), 331–357.
https://doi.org/10.1080/10641262.2011.603849

29. Broch, O. J., Alver, M. O., Bekkby, T., Gundersen, H., Forbord, S., Handå, A., Skjermo, J., & Hancke, K. (2019). The kelp cultivation potential in coastal and offshore regions of Norway. Frontiers in Marine Science, 5.
https://doi.org/10.3389/fmars.2018.00529

30. Brugere, C., Msuya, F. E., Jiddawi, N., Nyonje, B., & Maly, R. (2020). Can innovation empower? Reflections on introducing tubular nets to women seaweed farmers in Zanzibar. Gender, Technology and Development, 24(1), 89–109.
https://doi.org/10.1080/09718524.2019.1695307

31. Bruhn, A., Tørring, D. B., Thomsen, M., Canal-Vergés, P., Nielsen, M. M., Rasmussen, M. B., Eybye, K. L., Larsen, M. M., Balsby, T. J. S., & Petersen, J. K. (2016). Impact of environmental conditions on biomass yield, quality, and bio-mitigation capacity of Saccharina latissima. Aquaculture Environment Interactions, 8, 619–636.
https://doi.org/10.3354/aei00200

32. Buck, B.H., & Buchholz, C. M. (2005). Response of offshore cultivated Laminaria saccharina to hydrodynamic forcing in the North Sea. Aquaculture (Amsterdam, Netherlands), 250(3–4), 674–691.
https://doi.org/10.1016/j.aquaculture.2005.04.062

33. Buschmann, A. H., Prescott, S., Potin, P., Faugeron, S., Vásquez, J. A., Camus, C., Infante, J., Hernández-González, M. C., Gutíerrez, A., & Varela, D. A. (2014). The status of kelp exploitation and marine agronomy, with emphasis on Macrocystis pyrifera, in Chile. In Advances in Botanical Research (pp. 161–188). Elsevier.

34. Cabral, P., Levrel, H., Viard, F., Frangoudes, K., Girard, S., & Scemama, P. (2016). Ecosystem services assessment and compensation costs for installing seaweed farms. Marine Policy, 71, 157–165.
https://doi.org/10.1016/j.marpol.2016.05.031

35. Calheiros, A. C., Sales, L. P. M., Pereira Netto, A. D., Cavalcanti, D. N., Castelar, B., & Reis, R. P. (2021). Commercial raw materials from algaculture and natural stocks of Ulva spp. Journal of Applied Phycology, 33(3), 1805–1818.
https://doi.org/10.1007/s10811-021-02413-3

36. Campbell, I., Kambey, C. S. B., Mateo, J. P., Rusekwa, S. B., Hurtado, A. Q., Msuya, F. E., Stentiford, G. D., & Cottier-Cook, E. J. (2020). Biosecurity policy and legislation for the global seaweed aquaculture industry. Journal of Applied Phycology, 32(4), 2133–2146.
https://doi.org/10.1007/s10811-019-02010-5

37. Campos, C. V. F. da S., Moraes, L. B. S. de, Farias, R. da S., Severi, W., Brito, L. O., & Gálvez, A. O. (2019). Phytoplankton communities in aquaculture system (integration of shrimp and seaweed). Chemistry in Ecology, 35(10), 903–921.
https://doi.org/10.1080/02757540.2019.1668378

38. Chai, Z. Y., He, Z. L., Deng, Y. Y., Yang, Y. F., & Tang, Y. Z. (2018). Cultivation of seaweed Gracilaria lemaneiformis enhanced biodiversity in a eukaryotic plankton community as revealed via metagenomic analyses. Molecular Ecology, 27(4), 1081–1093.
https://doi.org/10.1111/mec.14496

39. Charlier, R. H., & Beavis, A. M. (2000). Development of a nearshore weed-screen. A nature coastal defence idea. The International Journal of Environmental Studies, 57(4), 457–468.
https://doi.org/10.1080/00207230008711289

40. Ajjabi, C.L., Abaab, M., & Segni, R. (2018). The red macroalga Gracilaria verrucosa in co-culture with the Mediterranean mussels Mytilus galloprovincialis: productivity and nutrient removal performance. Aquaculture International: Journal of the European Aquaculture Society, 26(1), 253–266.
https://doi.org/10.1007/s10499-017-0206-2

41. Chow, F., Macchiavello, J., Cruz, S. S., Fonck, E., & Olivares, J. (2001). Utilization of Gracilaria chilensis (Rhodophyta: Gracilariaceae) as a biofilter in the depuration of effluents from tank cultures of fish, oysters, and sea urchins. Journal of the World Aquaculture Society, 32(2), 215–220.
https://doi.org/10.1111/j.1749-7345.2001.tb01098.x

42. Clements, J. C., & Chopin, T. (2017). Ocean acidification and marine aquaculture in North America: potential impacts and mitigation strategies. Reviews in Aquaculture, 9(4), 326–341.
https://doi.org/10.1111/raq.12140

43. Cooke, M.F. (2004). Symbolic and social dimensions in the economic production of seaweed. Asia Pacific Viewpoint, 45(3), 387–400.
https://doi.org/10.1111/j.1467-8373.2004.00246.x

44. Cuaton, G. P. (2019). A post-disaster gendered value chain analysis on seaweed farming after Super Typhoon Haiyan in the Philippines. Journal of Enterprising Communities People and Places in the Global Economy, 13(4), 508–524.
https://doi.org/10.1108/jec-11-2018-0091

45. de Carvalho, L.L., de Souza, E.G.A., da Mata Júnior, M. R., & Villaça, R.C. (2017). Assessment of rocky reef fish assemblages close to seaweed farming. Aquaculture Research, 48(2), 481–493.
https://doi.org/10.1111/are.12896

46. Demel, S., Longo, A., & Mariel, P. (2020). Trading off visual disamenity for renewable energy: Willingness to pay for seaweed farming for energy production. Ecological Economics: The Journal of the International Society for Ecological Economics, 173(106650), 106650.
https://doi.org/10.1016/j.ecolecon.2020.106650

47. Diatin, I., Effendi, I., & Alvina Taufik, M. (2020). The production function and profitability analysis of Gracilaria sp. seaweed polyculture with milkfish (Chanos chanos) and black tiger shrimp (Penaeus monodon). Biodiversitas: Journal of Biological Diversity, 21(10).
https://doi.org/10.13057/biodiv/d211039

48. Dickson, R., Brigljevic, B., Lim, H., & Liu, J. (2020). Maximizing the sustainability of a macroalgae biorefinery: a superstructure optimization of a volatile fatty acid platform. Green Chemistry: An International Journal and Green Chemistry Resource: GC, 22(13), 4174–4186.
https://doi.org/10.1039/d0gc00430h

49. Dumilag, R. V., Salvador, R. C., & Halling, C. (2016). Genotype introduction affects population composition of native Philippine Kappaphycus (Gigartinales, Rhodophyta). Conservation Genetics Resources, 8(4), 439–441.
https://doi.org/10.1007/s12686-016-0591-2

50. Eklöf, J. S., de la Torre Castro, M., Adelsköld, L., Jiddawi, N. S., & Kautsky, N. (2005). Differences in macrofaunal and seagrass assemblages in seagrass beds with and without seaweed farms. Estuarine, Coastal and Shelf Science, 63(3), 385–396.
https://doi.org/10.1016/j.ecss.2004.11.014

51. Eklöf, J. S., Henriksson, R., & Kautsky, N. (2006). Effects of tropical open-water seaweed farming on seagrass ecosystem structure and function. Marine Ecology Progress Series, 325, 73–84.
https://doi.org/10.3354/meps325073

52. Eklöf, J.S., de la Torre-Castro, M., Nilsson, C., & Rönnbäck, P. (2006). How do seaweed farms influence local fishery catches in a seagrass-dominated setting in Chwaka Bay, Zanzibar? Aquatic Living Resources, 19(2), 137–147.
https://doi.org/10.1051/alr:2006013

53. Faisan, J. P., Jr, Luhan, M. R. J., Sibonga, R. C., Mateo, J. P., Ferriols, V. M. E. N., Brakel, J., Ward, G. M., Ross, S., Bass, D., Stentiford, G. D., Brodie, J., & Hurtado, A. Q. (2021). Preliminary survey of pests and diseases of eucheumatoid seaweed farms in the Philippines. Journal of Applied Phycology, 33(4), 2391–2405.
🔗 https://doi.org/10.1007/s10811-021-02481-5

54. Fan, L. I. N., Meirong, D. U., Hui, L. I. U., Jianguang, F. A. N. G., Lars, A., & Zengjie, J. I. A. N. G. (2020). A physical-biological coupled ecosystem model for integrated aquaculture of bivalve and seaweed in Sanggou Bay. Ecological Modelling, 431(109181), 109181.
🔗 https://doi.org/10.1016/j.ecolmodel.2020.109181

55. Fan, S., Fu, M., Wang, Z., Zhang, X., Song, W., Li, Y., Liu, G., Shi, X., Wang, X., & Zhu, M. (2015). Temporal variation of green macroalgal assemblage on Porphyra aquaculture rafts in the Subei Shoal, China. Estuarine, Coastal and Shelf Science, 163, 23–28.
🔗 https://doi.org/10.1016/j.ecss.2015.03.016

56. Fan, W., Zhang, Z., Yao, Z., Xiao, C., Zhang, Y., Zhang, Y., Liu, J., Di, Y., Chen, Y., & Pan, Y. (2020). A sea trial of enhancing carbon removal from Chinese coastal waters by stimulating seaweed cultivation through artificial upwelling. Applied Ocean Research, 101(102260), 102260.
🔗 https://doi.org/10.1016/j.apor.2020.102260

57. Fan, W., Zhao, R., Yao, Z., Xiao, C., Pan, Y., Chen, Y., Jiao, N., & Zhang, Y. (2019). Nutrient removal from Chinese coastal waters by large-scale seaweed aquaculture using artificial upwelling. Water, 11(9), 1754.
🔗 https://doi.org/10.3390/w11091754

58. Fasahati, P., Saffron, C. M., Woo, H. C., & Liu, J. J. (2017). Potential of brown algae for sustainable electricity production through anaerobic digestion. Energy Conversion and Management, 135, 297–307.
🔗 https://doi.org/10.1016/j.enconman.2016.12.084

59. Fernandes, F., Barbosa, M., Oliveira, A. P., Azevedo, I. C., Sousa-Pinto, I., Valentão, P., & Andrade, P. B. (2016). The pigments of kelps (Ochrophyta) as part of the flexible response to highly variable marine environments. Journal of Applied Phycology, 28(6), 3689–3696.
🔗 https://doi.org/10.1007/s10811-016-0883-7

60. Fernandes, H., Salgado, J. M., Martins, N., Peres, H., Oliva-Teles, A., & Belo, I. (2019). Sequential bioprocessing of Ulva rigida to produce lignocellulolytic enzymes and to improve its nutritional value as aquaculture feed. Bioresource Technology, 281, 277–285.
🔗 https://doi.org/10.1016/j.biortech.2019.02.068

61. Figueira, T. A., Martins, N. T., Ayres-Ostrock, L., Plastino, E. M., Enrich-Prast, A., & Oliveira, V. P. de. (2021). The effects of phosphate on physiological responses and carbohydrate production in Ulva fasciata (Chlorophyta) from upwelling and non-upwelling sites. Botanica Marina, 64(1), 1–11.
🔗 https://doi.org/10.1515/bot-2020-0051

62. Flaherty, M., Reid, G., Chopin, T., & Latham, E. (2019). Public attitudes towards marine aquaculture in Canada: insights from the Pacific and Atlantic coasts. Aquaculture International: Journal of the European Aquaculture Society, 27(1), 9–32.
🔗 https://doi.org/10.1007/s10499-018-0312-9

63. Forbord, S., Matsson, S., Brodahl, G. E., Bluhm, B. A., Broch, O. J., Handå, A., Metaxas, A., Skjermo, J., Steinhovden, K. B., & Olsen, Y. (2020). Latitudinal, seasonal and depth-dependent variation in growth, chemical composition and biofouling of cultivated Saccharina latissima (Phaeophyceae) along the Norwegian coast. Journal of Applied Phycology, 32(4), 2215–2232.
🔗 https://doi.org/10.1007/s10811-020-02038-y

64. Forbord, S., Skjermo, J., Arff, J., Handå, A., Reitan, K. I., Bjerregaard, R., & Lüning, K. (2012). Development of Saccharina latissima (Phaeophyceae) kelp hatcheries with year-round production of zoospores and juvenile sporophytes on culture ropes for kelp aquaculture. Journal of Applied Phycology, 24(3), 393–399.
🔗 https://doi.org/10.1007/s10811-011-9784-y

65. Freitas, J. R. C., Jr, Salinas Morrondo, J. M., & Cremades Ugarte, J. (2016). Saccharina latissima (Laminariales, Ochrophyta) farming in an industrial IMTA system in Galicia (Spain). Journal of Applied Phycology, 28(1), 377–385.
🔗 https://doi.org/10.1007/s10811-015-0526-4

66. Fröcklin, S., de la Torre-Castro, M., Lindström, L., Jiddawi, N. S., & Msuya, F. E. (2012). Seaweed mariculture as a development project in Zanzibar, East Africa: A price too high to pay? Aquaculture (Amsterdam, Netherlands), 356–357, 30–39.
🔗 https://doi.org/10.1016/j.aquaculture.2012.05.039

67. Ganzon-Fortes, E. T., Trono, G. C., Jr, Villanueva, R. D., Romero, J. B., & Montaño, M. N. E. (2012). 'Endong', a rare variety of the farmed carrageenophyte Eucheuma denticulatum (Burman) Collins & Hervey from the Philippines. Journal of Applied Phycology, 24(5), 1107–1111.
🔗 https://doi.org/10.1007/s10811-011-9740-x

68. Gao, Y., Zhang, Y., Du, M., Lin, F., Jiang, W., Li, W., Li, F., Lv, X., Fang, J., & Jiang, Z. (2021). Dissolved organic carbon from cultured kelp Saccharina japonica: production, bioavailability, and bacterial degradation rates. Aquaculture Environment Interactions.
🔗 https://doi.org/10.3354/aei00393

69. Ge, H.X., Ni, Q., Li, J., Li, J.T., Chen, Z., & Zhao, F.-Z. (2019). Integration of white shrimp (Litopenaeus vannamei) and green seaweed (Ulva prolifera) in minimum-water exchange aquaculture system. Journal of Applied Phycology, 31(2), 1425–1432.
🔗 https://doi.org/10.1007/s10811-018-1601-4

70. Geo, L.O., Halim, & Rachmasari Ariani, W. O. (2020). Farming production analysis of seaweed and farmer's perception towards climate change effect in Southeast Sulawesi, Indonesia. Pakistan Journal of Biological Sciences: PJBS, 23(8), 1004–1009.
https://doi.org/10.3923/pjbs.2020.1004.1009

71. Ghosh, A., Vijay Anand, K. G., & Seth, A. (2015). Life cycle impact assessment of seaweed based biostimulant production from onshore cultivated Kappaphycus alvarezii (Doty) Doty ex Silva—Is it environmentally sustainable? Algal Research, 12, 513–521.
https://doi.org/10.1016/j.algal.2015.10.015

72. Ginigaddara, G. A. S., Lankapura, A. I. Y., Rupasena, L. P., & Bandara, A. M. K. (2018). Seaweed farming as a sustainable livelihood option for northern coastal communities in Sri Lanka. Future of Food: Journal on Food, Agriculture and Society, 6(1), 57–70.

73. Grebe, G.S., Byron, C.J., Gelais, A.S., Kotowicz, D.M., & Olson, T.K. (2019). An ecosystem approach to kelp aquaculture in the Americas and Europe. Aquaculture Reports, 15(100215), 100215.
https://doi.org/10.1016/j.aqrep.2019.100215

74. Gu, Y.G., Lin, Q., Lu, T.T., Ke, C.L., Sun, R.X., & Du, F.Y. (2013). Levels, composition profiles and sources of polycyclic aromatic hydrocarbons in surface sediments from Nan'ao Island, a representative mariculture base in South China. Marine Pollution Bulletin, 75(1–2), 310–316.
https://doi.org/10.1016/j.marpolbul.2013.07.039

75. Gupta, V., Trivedi, N., Simoni, S., & Reddy, C. R. K. (2018). Marine macroalgal nursery: A model for sustainable production of seedlings for large scale farming. Algal Research, 31, 463–468.
https://doi.org/10.1016/j.algal.2018.02.032

76. Hadley, S., Wild-Allen, K., Johnson, C., & Macleod, C. (2015). Modeling macroalgae growth and nutrient dynamics for integrated multi-trophic aquaculture. Journal of Applied Phycology, 27(2), 901–916.
https://doi.org/10.1007/s10811-014-0370-y

77. Hadley, S., Wild-Allen, K., Johnson, C., & Macleod, C. (2016). Quantification of the impacts of finfish aquaculture and bioremediation capacity of integrated multi-trophic aquaculture using a 3D estuary model. Journal of Applied Phycology, 28(3), 1875–1889.
https://doi.org/10.1007/s10811-015-0714-2

78. Halling, C., Aroca, G., Cifuentes, M., Buschmann, A. H., & Troell, M. (2005). Comparison of spore inoculated and vegetative propagated cultivation methods of Gracilaria chilensis in an integrated seaweed and fish cage culture. Aquaculture International: Journal of the European Aquaculture Society, 13(5), 409–422.
https://doi.org/10.1007/s10499-005-6977-x

79. Halling, C., Wikström, S.A., Lilliesköld-Sjöö, G., Mörk, E., Lundsør, E., & Zuccarello, G.C. (2013). Introduction of Asian strains and low genetic variation in farmed seaweeds: indications for new management practices. Journal of Applied Phycology, 25(1), 89–95.
https://doi.org/10.1007/s10811-012-9842-0

80. Han, H., Fan, S., Song, W., Li, Y., Xiao, J., Wang, Z., Zhang, X., & Ding, D. (2020). The contribution of attached Ulva prolifera on Pyropia aquaculture rafts to green tides in the Yellow Sea. Hai Yang Xue Bao [Acta Oceanologica Sinica], 39(2), 101–106.
https://doi.org/10.1007/s13131-019-1452-0

81. Han, W., Chen, L.-P., Zhang, J.-H., Tian, X.-L., Hua, L., He, Q., Huo, Y.-Z., Yu, K.-F., Shi, D.-J., Ma, J.-H., & He, P.-M. (2013). Seasonal variation of dominant free-floating and attached Ulva species in Rudong coastal area, China. Harmful Algae, 28, 46–54.
https://doi.org/10.1016/j.hal.2013.05.018

82. Handå, A., Forbord, S., Wang, X., Broch, O. J., Dahle, S. W., Størseth, T. R., Reitan, K. I., Olsen, Y., & Skjermo, J. (2013). Seasonal- and depth-dependent growth of cultivated kelp (Saccharina latissima) in close proximity to salmon (Salmo salar) aquaculture in Norway. Aquaculture (Amsterdam, Netherlands), 414–415, 191–201.
https://doi.org/10.1016/j.aquaculture.2013.08.006

83. Hao, Y., Qu, T., Guan, C., Zhao, X., Hou, C., Tang, X., & Wang, Y. (2020). Competitive advantages of Ulva prolifera from Pyropia aquaculture rafts in Subei Shoal and its implication for the green tide in the Yellow Sea. Marine Pollution Bulletin, 157(111353), 111353.
https://doi.org/10.1016/j.marpolbul.2020.111353

84. Harlina, H. (2021). Cultivation of seaweed using the basic stocking system in floating net cages on Salemo Island, Pangkep Regency, South Sulawesi, Indonesia. Aquaculture, Aquarium, Conservation & Legislation : International Journal of the Bioflux Society, 14(2), 976–980.

85. Hasselström, L., Thomas, J.B., Nordström, J., Cervin, G., Nylund, G.M., Pavia, H., & Gröndahl, F. (2020). Socioeconomic prospects of a seaweed bioeconomy in Sweden. Scientific Reports, 10(1), 1610.
https://doi.org/10.1038/s41598-020-58389-6

86. Hasselström, L., Visch, W., Gröndahl, F., Nylund, G. M., & Pavia, H. (2018). The impact of seaweed cultivation on ecosystem services - a case study from the west coast of Sweden. Marine Pollution Bulletin, 133, 53–64.
https://doi.org/10.1016/j.marpolbul.2018.05.005

87. Hayashi, L., Yokoya, N. S., Ostini, S., Pereira, R. T. L., Braga, E. S., & Oliveira, E. C. (2008). Nutrients removed by Kappaphycus alvarezii (Rhodophyta, Solieriaceae) in integrated cultivation with fishes in re-circulating water. Aquaculture (Amsterdam, Netherlands), 277(3–4), 185–191.
https://doi.org/10.1016/j.aquaculture.2008.02.024

88. He, P., Xu, S., Zhang, H., Wen, S., Dai, Y., Lin, S., & Yarish, C. (2008). Bioremediation efficiency in the removal of dissolved inorganic nutrients by the red seaweed, Porphyra yezoensis, cultivated in the open sea. Water Research, 42(4–5), 1281–1289.
https://doi.org/10.1016/j.watres.2007.09.023

89. Hedberg, N., von Schreeb, K., Charisiadou, S., Jiddawi, N. S., Tedengren, M., & Nordlund, L. M. (2018). Habitat preference for seaweed farming – A case study from Zanzibar, Tanzania. Ocean & Coastal Management, 154, 186–195.
https://doi.org/10.1016/j.ocecoaman.2018.01.016

90. Heery, E. C., Lian, K. Y., Loke, L. H. L., Tan, H. T. W., & Todd, P. A. (2020). Evaluating seaweed farming as an eco-engineering strategy for 'blue' shoreline infrastructure. Ecological Engineering, 152(105857), 105857.
https://doi.org/10.1016/j.ecoleng.2020.105857

91. Hehre, E. J., & Meeuwig, J. J. (2015). Differential response of fish assemblages to coral reef-based seaweed farming. PloS One, 10(3), e0118838.
https://doi.org/10.1371/journal.pone.0118838

92. Hehre, E. J., & Meeuwig, J. J. (2016). A global analysis of the relationship between farmed seaweed production and herbivorous fish catch. PloS One, 11(2), e0148250.
https://doi.org/10.1371/journal.pone.0148250

93. Hernández, I., Martínez-Aragón, J. F., Tovar, A., Pérez-Lloréns, J. L., & Vergara, J. J. (2002). Biofiltering efficiency in removal of dissolved nutrients by three species of estuarine macroalgae cultivated with seabass (Dicentrarchus labrax) with seawater. 2 Ammonium. Journal of Applied Phycology, 14(5), 375–384.
https://doi.org/10.1023/a:1022178417203

94. Hernández, I., Fernández-Engo, M.A., Pérez-Lloréns, J.L., & Vergara, J.J. (2005). Integrated outdoor culture of two estuarine macroalgae as biofilters for dissolved nutrients from Sparus auratus waste waters. Journal of Applied Phycology, 17(6), 557–567.
https://doi.org/10.1007/s10811-005-9006-6

95. Hill, N. A. O., Rowcliffe, J. M., Koldewey, H. J., & Milner-Gulland, E. J. (2012). The interaction between seaweed farming as an alternative occupation and fisher numbers in the central Philippines. Conservation Biology: The Journal of the Society for Conservation Biology, 26(2), 324–334.
https://doi.org/10.1111/j.1523-1739.2011.01796.x

96. Holdt, S. L., & Edwards, M. D. (2014). Cost-effective IMTA: a comparison of the production efficiencies of mussels and seaweed. Journal of Applied Phycology, 26(2), 933–945.
https://doi.org/10.1007/s10811-014-0273-y

97. Hossain, M. S., Sharifuzzaman, S. M., Nobi, M. N., Chowdhury, M. S. N., Sarker, S., Alamgir, M., Uddin, S. A., Chowdhury, S. R., Rahman, M. M., Rahman, M. S., Sobhan, F., & Chowdhury, S. (2021). Seaweeds farming for sustainable development goals and blue economy in Bangladesh. Marine Policy, 128(104469), 104469.
https://doi.org/10.1016/j.marpol.2021.104469

98. Hu, X., Wen, G., Cao, Y., Gong, Y., Li, Z., He, Z., & Yang, Y. (2017). Metabolic and phylogenetic profiles of microbial communities from a mariculture base on the Chinese Guangdong coast. Fisheries Science: FS, 83(3), 465–477.
https://doi.org/10.1007/s12562-017-1073-5

99. Hughes, A. D., Black, K. D., Campbell, I., Davidson, K., Kelly, M. S., & Stanley, M. S. (2012). Does seaweed offer a solution for bioenergy with biological carbon capture and storage? Greenhouse Gases Science and Technology, 2(6), 402–407.
https://doi.org/10.1002/ghg.1319

100. Huo, Y., Han, H., Hua, L., Wei, Z., Yu, K., Shi, H., Kim, J. K., Yarish, C., & He, P. (2016). Tracing the origin of green macroalgal blooms based on the large scale spatio-temporal distribution of Ulva microscopic propagules and settled mature Ulva vegetative thalli in coastal regions of the Yellow Sea, China. Harmful Algae, 59, 91–99.
https://doi.org/10.1016/j.hal.2016.09.005

101. Huo, Y., Han, H., Shi, H., Wu, H., Zhang, J., Yu, K., Xu, R., Liu, C., Zhang, Z., Liu, K., He, P., & Ding, D. (2015). Changes to the biomass and species composition of Ulva sp. on Porphyra aquaculture rafts, along the coastal radial sandbank of the Southern Yellow Sea. Marine Pollution Bulletin, 93(1–2), 210–216.
https://doi.org/10.1016/j.marpolbul.2015.01.014

102. Hurtado, A. Q., Critchley, A. T., Trespoey, A., & Lhonneur, G. B. (2006). Occurrence of Polysiphonia epiphytes in Kappaphycus farms at calaguas Is., Camarines Norte, Phillippines. Journal of Applied Phycology, 18(3–5), 301–306.
https://doi.org/10.1007/s10811-006-9032-z

103. Hussin, R., Yasir, S., & Kunjuraman, V. (2015). Potential of seaweed cultivation as a community-based rural tourism product: a stakeholders' perspectives. Advances in Environmental Biology, 154+.

104. Israel, A., Gavrieli, J., Glazer, A., & Friedlander, M. (2005). Utilization of flue gas from a power plant for tank cultivation of the red seaweed Gracilaria cornea. Aquaculture (Amsterdam, Netherlands), 249(1–4), 311–316.
https://doi.org/10.1016/j.aquaculture.2005.04.058

105. Jacob, C.T., & Reddy, C.A. (2015). Implementation of the Access and Benefit Sharing provisions of the Biological Diversity act, 2002: A case study on red seaweed (Kappaphycus alvarezii). Asian Biotechnology and Development Review, 17(3), 39–51.

106. Jiang, Z., Fang, J., Mao, Y., Han, T., & Wang, G. (2013). Influence of seaweed aquaculture on marine inorganic carbon dynamics and sea-air CO2 flux: Seaweed aquaculture and inorganic carbon dynamics. Journal of the World Aquaculture Society, 44(1), 133–140.
https://doi.org/10.1111/jwas.12000

107. Jiang, Z., Liu, J., Li, S., Chen, Y., Du, P., Zhu, Y., Liao, Y., Chen, Q., Shou, L., Yan, X., Zeng, J., & Chen, J. (2020). Kelp cultivation effectively improves water quality and regulates phytoplankton community in a turbid, highly eutrophic bay. The Science of the Total Environment, 707(135561), 135561.
https://doi.org/10.1016/j.scitotenv.2019.135561

108. Jonouchi, K., Yokoyama, S., Imou, K., & Kaizu, Y. (2006). Utilization of marine biomass for bioenergy: Fuel cell power generation driven by biogas derived from seaweed. International Energy Journal, 7(3).

109. Jung, K. A., Lim, S.-R., Kim, Y., & Park, J. M. (2017). Opportunity and challenge of seaweed bioethanol based on life cycle CO2 assessment. Environmental Progress & Sustainable Energy, 36(1), 200–207.
https://doi.org/10.1002/ep.12446

110. Kadowaki, S., & Kitadai, Y. (2017). Advantages of environmentally sound poly-eco-aquaculture in fish farms. In Application of Recirculating Aquaculture Systems in Japan (pp. 267–278). Springer Japan.

111. Kambey, C. S. B., Campbell, I., Sondak, C. F. A., Nor, A. R. M., Lim, P. E., & Cottier-Cook, E. J. (2020). An analysis of the current status and future of biosecurity frameworks for the Indonesian seaweed industry. Journal of Applied Phycology, 32(4), 2147–2160.
https://doi.org/10.1007/s10811-019-02020-3

112. Kambey, C. S. B., Sondak, C. F. A., & Chung, I.-K. (2020). Potential growth and nutrient removal of Kappaphycus alvarezii in a fish floating-net cage system in Sekotong Bay, Lombok, Indonesia. Journal of the World Aquaculture Society, 51(4), 944–959.
https://doi.org/10.1111/jwas.12683

113. Kang, Y. H., Kim, S., Choi, S. K., Lee, H. J., Chung, I. K., & Park, S. R. (2021). A comparison of the bioremediation potential of five seaweed species in an integrated fish-seaweed aquaculture system: implication for a multi-species seaweed culture. Reviews in Aquaculture, 13(1), 353–364.
https://doi.org/10.1111/raq.12478

114. Kasan, N. A., Zainoddin, J., Mohd Lazim, M. S., Saberi, M., Huda Moham, N. A., & Ikhwanuddi, M. (2018). Carbon sink profile in cultured seaweed, Gracilaria changii for mitigation of global warming phenomenon. Journal of Environmental Science and Technology, 11(4), 190–198.
https://doi.org/10.3923/jest.2018.190.198

115. Kasim, M., Mustafa, A., Ishak, E., Ibrahim, M. N., & Irawati, N. (2019). Environmental status of Kappaphycus alvarezii cultivation area following temporary eutrophication. In Aquaculture, Aquarium, Conservation & Legislation Bioflux, 12 (4), pp. 1102–1113).

116. Keesing, J. K., Liu, D., Fearns, P., & Garcia, R. (2011). Inter- and intra-annual patterns of Ulva prolifera green tides in the Yellow Sea during 2007-2009, their origin and relationship to the expansion of coastal seaweed aquaculture in China. Marine Pollution Bulletin, 62(6), 1169–1182.
https://doi.org/10.1016/j.marpolbul.2011.03.040

117. Keesing, J. K., Liu, D., Shi, Y., & Wang, Y. (2016). Abiotic factors influencing biomass accumulation of green tide causing Ulva spp. on Pyropia culture rafts in the Yellow Sea, China. Marine Pollution Bulletin, 105(1), 88–97.
https://doi.org/10.1016/j.marpolbul.2016.02.051

118. Keng, F. S.L., Phang, S.M., Abd Rahman, N., Elvidge, E.C.L., Malin, G., & Sturges, W. T. (2020). The emission of volatile halocarbons by seaweeds and their response towards environmental changes. Journal of Applied Phycology, 32(2), 1377–1394.
https://doi.org/10.1007/s10811-019-02026-x

119. Kerrison, P. D., Stanley, M. S., & Hughes, A. D. (2018). Textile substrate seeding of Saccharina latissima sporophytes using a binder: An effective method for the aquaculture of kelp. Algal Research, 33, 352–357.
https://doi.org/10.1016/j.algal.2018.06.005

120. Kersen, P., Paalme, T., Pajusalu, L., & Martin, G. (2017). Biotechnological applications of the red alga Furcellaria lumbricalis and its cultivation potential in the Baltic Sea. Botanica Marina, 60(2).
https://doi.org/10.1515/bot-2016-0062

121. Kim, J. B., Lee, W.-C., Kim, H. C., & Hong, S. (2020). Photosynthetic characteristics of Pyropia yezoensis (Ueda) Hwang & Choi measured using Diving-PAM in the Jindo-Haenam region on the southwestern coast of the Korean Peninsula. Journal of Applied Phycology, 32(4), 2631–2640.
https://doi.org/10.1007/s10811-019-01997-1

122. Kim, J.K., Kraemer, G.P., & Yarish, C. (2015). Use of sugar kelp aquaculture in Long Island Sound and the Bronx River Estuary for nutrient extraction. Marine Ecology Progress Series, 531, 155–166.
https://doi.org/10.3354/meps11331

123. Kim, J.K., Kraemer, G.P., & Yarish, C. (2014). Field scale evaluation of seaweed aquaculture as a nutrient bioextraction strategy in Long Island Sound and the Bronx River Estuary. Aquaculture (Amsterdam, Netherlands), 433, 148–156.
https://doi.org/10.1016/j.aquaculture.2014.05.034

124. Korzen, L., Abelson, A., & Israel, A. (2016). Growth, protein and carbohydrate contents in Ulva rigida and Gracilaria bursa-pastoris integrated with an offshore fish farm. Journal of Applied Phycology, 28(3), 1835–1845.
https://doi.org/10.1007/s10811-015-0691-5

125. Korzen, L., Peled, Y., Shamir, S. Z., Shechter, M., Gedanken, A., Abelson, A., & Israel, A. (2015). An economic analysis of bioethanol production from the marine macroalga Ulva (Chlorophyta). Technology, 03(02n03), 114–118.
https://doi.org/10.1142/s2339547815400105

126. Kraan, S., & Barrington, K. A. (2005). Commercial farming of Asparagopsis armata (Bonnemaisoniceae, Rhodophyta) in Ireland, maintenance of an introduced species? Journal of Applied Phycology, 17(2), 103–110. https://doi.org/10.1007/s10811-005-2799-5

127. Krishnan, P., Abhilash, K. R., Sreeraj, C. R., Samuel, V. D., Purvaja, R., Anand, A., Mahapatra, M., Sankar, R., Raghuraman, R., & Ramesh, R. (2021). Balancing livelihood enhancement and ecosystem conservation in seaweed farmed areas: A case study from Gulf of Mannar Biosphere Reserve, India. Ocean & Coastal Management, 207(105590), 105590. https://doi.org/10.1016/j.ocecoaman.2021.105590

128. Krumhansl, K. A., Bergman, J. N., & Salomon, A. K. (2017). Assessing the ecosystem-level consequences of a small-scale artisanal kelp fishery within the context of climate-change. Ecological Applications: A Publication of the Ecological Society of America, 27(3), 799–813. https://doi.org/10.1002/eap.1484

129. Kübler, J. E., Dudgeon, S. R., & Bush, D. (2021). Climate change challenges and opportunities for seaweed aquaculture in California, the United States. Journal of the World Aquaculture Society, 52(5), 1069–1080. https://doi.org/10.1111/jwas.12794

130. Kuhnen, V. V., Costa, L. de G., Raiol, K. de L., Souza, O. M., & Sanches, E. G. (2019). Mariculture impacts on the benthonic icthyofauna of Itaguá bay, Ubatuba, southeast Brazil. Boletim Do Instituto de Pesca São Paulo, 45(4), e500. https://doi.org/10.20950/1678-2305.2019.45.4.500

131. Kunjuraman, V., Hossin, A., Hussin, R. (2019). Women in Malaysian seaweed industry: Motivations and impacts. Kajian Malaysia, 37(2), 49–74. https://doi.org/10.21315/km2019.37.2.3

132. Lampe, M., Munsi, H., & Luran, N. F. (2020). Development phases and socio-cultural contexts of the reef-based fishing economy of the Sembilan Islands community, South Sulawesi, Indonesia. Aquaculture, Aquarium, Conservation & Legislation Bioflux, 13(2), 459-469

133. Lamprianidou, F., Telfer, T., & Ross, L. G. (2015). A model for optimization of the productivity and bioremediation efficiency of marine integrated multitrophic aquaculture. Estuarine, Coastal and Shelf Science, 164, 253–264.

https://doi.org/10.1016/j.ecss.2015.07.045

134. Larson, S., Stoeckl, N., Fachry, M. E., Dalvi Mustafa, M., Lapong, I., Purnomo, A. H., Rimmer, M. A., & Paul, N. A. (2021). Women's well-being and household benefits from seaweed farming in Indonesia. Aquaculture (Amsterdam, Netherlands), 530(735711), 735711. https://doi.org/10.1016/j.aquaculture.2020.735711

135. Lehahn, Y., Ingle, K. N., & Golberg, A. (2016). Global potential of offshore and shallow waters macroalgal biorefineries to provide for food, chemicals and energy: feasibility and sustainability. Algal Research, 17, 150–160. https://doi.org/10.1016/j.algal.2016.03.031

136. Lei, Y., Feng, P., Du, X., & Jiang, S. (2021). Diatom assemblages from sediment traps in response to large seaweed Gracilaria cultivation off Nan'ao island, South China. Marine Pollution Bulletin, 165(112157), 112157. https://doi.org/10.1016/j.marpolbul.2021.112157

137. Li, Q., Shan, T., Wang, X., Su, L., & Pang, S. (2020). Evaluation of the genetic relationship between the farmed populations on a typical kelp farm and the adjacent subtidal spontaneous population of Undaria pinnatifida (Phaeophyceae, Laminariales) in China. Journal of Applied Phycology, 32(1), 653–659. https://doi.org/10.1007/s10811-019-01917-3

138. Limi, M. A., Sara, L., La Ola, T., Yunus, L., Suriana, T. S. A. A., Batoa, H., Hamzah, A., Fyka, S. A., & Prapitasari, M. (2018). The production and income from seaweed farming after the sedimentation in Kendari Bay. Aquaculture, Aquarium, Conservation & Legislation Bioflux, 11(6), 1927-1936

139. Liu, D., Keesing, J. K., Dong, Z., Zhen, Y., Di, B., Shi, Y., Fearns, P., & Shi, P. (2010). Recurrence of the world's largest green-tide in 2009 in Yellow Sea, China: Porphyra yezoensis aquaculture rafts confirmed as nursery for macroalgal blooms. Marine Pollution Bulletin, 60(9), 1423–1432. https://doi.org/10.1016/j.marpolbul.2010.05.015

140. Liu, D., Keesing, J. K., He, P., Wang, Z., Shi, Y., & Wang, Y. (2013). The world's largest macroalgal bloom in the Yellow Sea, China: Formation and implications. Estuarine, Coastal and Shelf Science, 129, 2–10. https://doi.org/10.1016/j.ecss.2013.05.021

141. Liu, D., Keesing, J. K., Xing, Q., & Shi, P. (2009). World's largest macroalgal bloom caused by expansion of seaweed aquaculture in China. Marine Pollution Bulletin, 58(6), 888–895. https://doi.org/10.1016/j.marpolbul.2009.01.013

142. Liu, J., Xia, J., Zhuang, M., Zhang, J., Sun, Y., Tong, Y., Zhao, S., & He, P. (2021). Golden seaweed tides accumulated in Pyropia aquaculture areas are becoming a normal phenomenon in the Yellow Sea of China. The Science of the Total Environment, 774(145726), 145726. https://doi.org/10.1016/j.scitotenv.2021.145726

143. Liu, Z., Luo, H., Wu, Y., Ren, H., & Yang, Y. (2019). Large-scale cultivation of Gracilaria lemaneiformis in Nan'ao Island of Shantou and its effects on the aquatic environment and phytoplankton. Journal of Fishery Sciences of China, 26(1), 99. https://doi.org/10.3724/sp.j.1118.2019.18373

144. Macchiavello, J., & Bulboa, C. (2014). Nutrient uptake efficiency of Gracilaria chilensis and Ulva lactuca in an IMTA system with the red abalone Haliotis rufescens. Latin American Journal of Aquatic Research, 42(3), 523–533.
🔗 https://doi.org/10.3856/vol42-issue3-fulltext-12

145. Magnusson, M., Mata, L., de Nys, R., & Paul, N. A. (2014). Biomass, lipid and fatty acid production in large-scale cultures of the marine macroalga Derbesia tenuissima (Chlorophyta). Marine Biotechnology (New York, N.Y.), 16(4), 456–464.
🔗 https://doi.org/10.1007/s10126-014-9564-1

146. Mahmood, T., Fang, J., Jiang, Z., & Zhang, J. (2016). Carbon and nitrogen flow, and trophic relationships, among the cultured species in an integrated multi-trophic aquaculture (IMTA) bay. Aquaculture Environment Interactions, 8, 207–219.
🔗 https://doi.org/10.3354/aei00152

147. Mahmood, Tariq, Fang, J., Jiang, Z., Ying, W., & Zhang, J. (2017). Seasonal distribution, sources and sink of dissolved organic carbon in integrated aquaculture system in coastal waters. Aquaculture International: Journal of the European Aquaculture Society, 25(1), 71–85.
🔗 https://doi.org/10.1007/s10499-016-0014-0

148. Marinho-Soriano, Moreira, & Carneiro. (2006). Some aspects of the growth of Gracilaria birdiae (Gracilariales, Rhodophyta) in an estuary in northeast Brazil. Aquaculture International: Journal of the European Aquaculture Society, 14(4), 327–336.
🔗 https://doi.org/10.1007/s10499-005-9032-z

149. Martínez-Aragón, J. F., Hernández, I., Pérez-Lloréns, J. L., Vázquez, R., & Vergara, J. J. (2002). Journal of Applied Phycology, 14(5), 365–374.
🔗 https://doi.org/10.1023/a:1022134701273

150. Mata, L., Gaspar, H., & Santos, R. (2012). Carbon/nutrient balance in relation to biomass production and halogenated compound content in the red alga Asparagopsis taxiformis (Bonnemaisoniaceae) Journal of Phycology, 48(1), 248–253.
🔗 https://doi.org/10.1111/j.1529-8817.2011.01083.x

151. Mata, L., Schuenhoff, A., & Santos, R. (2010). A direct comparison of the performance of the seaweed biofilters, Asparagopsis armata and Ulva rigida. Journal of Applied Phycology, 22(5), 639–644.
🔗 https://doi.org/10.1007/s10811-010-9504-z

152. Mateo, J. P., Campbell, I., Cottier-Cook, E. J., Luhan, M. R. J., Ferriols, V. M. E. N., & Hurtado, A. Q. (2020). Analysis of biosecurity-related policies governing the seaweed industry of the Philippines. Journal of Applied Phycology, 32(3), 2009–2022.
🔗 https://doi.org/10.1007/s10811-020-02083-7

153. Matsson, S., Christie, H., & Fieler, R. (2019). Variation in biomass and biofouling of kelp, Saccharina latissima, cultivated in the Arctic, Norway. Aquaculture (Amsterdam, Netherlands), 506, 445–452.
🔗 https://doi.org/10.1016/j.aquaculture.2019.03.068

154. Mhatre, A., Navale, M., Trivedi, N., Pandit, R., & Lali, A. M. (2018). Pilot scale flat panel photobioreactor system for mass production of Ulva lactuca (Chlorophyta). Bioresource Technology, 249, 582–591.
🔗 https://doi.org/10.1016/j.biortech.2017.10.058

155. Miao, X., Xiao, J., Xu, Q., Fan, S., Wang, Z., Wang, X., & Zhang, X. (2020). Distribution and species diversity of the floating green macroalgae and micro-propagules in the Subei Shoal, southwestern Yellow Sea. PeerJ, 8(e10538), e10538.
🔗 https://doi.org/10.7717/peerj.10538

156. Michler-Cieluch, T., & Kodeih, S. (2008). Mussel and seaweed cultivation in offshore wind farms: An opinion survey. Coastal Management: An International Journal of Marine Environment, Resources, Law, and Society, 36(4), 392–411.
🔗 https://doi.org/10.1080/08920750802273185

157. Mirera, D. O., Kimathi, A., Ngarari, M. M., Magondu, E. W., Wainaina, M., & Ototo, A. (2020). Societal and environmental impacts of seaweed farming in relation to rural development: The case of Kibuyuni village, south coast, Kenya. Ocean & Coastal Management, 194(105253), 105253.
🔗 https://doi.org/10.1016/j.ocecoaman.2020.105253

158. Mithoo-Singh, P. K., Keng, F. S.-L., Phang, S.-M., Leedham Elvidge, E. C., Sturges, W. T., Malin, G., & Abd Rahman, N. (2017). Halocarbon emissions by selected tropical seaweeds: species-specific and compound-specific responses under changing pH. PeerJ, 5(e2918).
🔗 https://doi.org/10.7717/peerj.2918

159. Mongin, M., Baird, M. E., Hadley, S., & Lenton, A. (2016). Optimising reef-scale CO2 removal by seaweed to buffer ocean acidification. Environmental Research Letters, 11(3), 034023.
🔗 https://doi.org/10.1088/1748-9326/11/3/034023

160. Monteiro, J. P., Melo, T., Skjermo, J., Forbord, S., Broch, O. J., Domingues, P., Calado, R., & Domingues, M. R. (2021). Effect of harvesting month and proximity to fish farm sea cages on the lipid profile of cultivated Saccharina latissima. Algal Research, 54(102201), 102201.
🔗 https://doi.org/10.1016/j.algal.2021.102201

161. Mooney, K. M., Beatty, G. E., Elsäßer, B., Follis, E. S., Kregting, L., O'Connor, N. E., Riddell, G. E., & Provan, J. (2018). Hierarchical structuring of genetic variation at differing geographic scales in the cultivated sugar kelp Saccharina latissima. Marine Environmental Research, 142, 108–115.
🔗 https://doi.org/10.1016/j.marenvres.2018.09.029

162. Moreira-Saporiti, A., Hoeijmakers, D., Msuya, F. E., Reuter, H., & Teichberg, M. (2021). Seaweed farming pressure affects seagrass and benthic macroalgae dynamics in Chwaka Bay (Zanzibar, Tanzania). Regional Environmental Change, 21(1).
https://doi.org/10.1007/s10113-020-01742-2

163. Msuya, F. E., & Porter, M. (2014). Impact of environmental changes on farmed seaweed and farmers: the case of Songo Songo Island, Tanzania. Journal of Applied Phycology, 26(5), 2135–2141.
https://doi.org/10.1007/s10811-014-0243-4

164. Mulyani, S., Tuwo, A., Syamsuddin, R., & Jompa, J. (2018). Effect of seaweed Kappaphycus alvarezii aquaculture on growth and survival of coral Acropora muricata. Aquaculture, Aquarium, Conservation & Legislation Bioflux, 11(6), 1792-1798.

165. Mulyani, S., Tuwo, A., Syamsuddin, R., Jompa, J., & Cahyono, I. (2020). Effect of Kappaphycus alvarezii mariculture on the recruitment of scleractinian corals. Aquaculture, Aquarium, Conservation & Legislation Bioflux, 13(3), 1746–1757.

166. Muñoz, J., Freile-Pelegrín, Y., & Robledo, D. (2004). Mariculture of Kappaphycus alvarezii (Rhodophyta, Solieriaceae) color strains in tropical waters of Yucatán, México. Aquaculture (Amsterdam, Netherlands), 239(1–4), 161–177.
https://doi.org/10.1016/j.aquaculture.2004.05.043

167. Nagler, P.L., Glenn, E.P., Nelson, S.G., & Napolean, S. (2003). Effects of fertilization treatment and stocking density on the growth and production of the economic seaweed Gracilaria parvispora (Rhodophyta) in cage culture at Molokai, Hawaii. Aquaculture (Amsterdam, Netherlands), 219(1–4), 379–391.
https://doi.org/10.1016/s0044-8486(02)00529-x

168. Namudu, M. T., & Pickering, T. D. (2006). Rapid survey technique using Socio-economic indicators to assess the suitability of pacific island rural communities for Kappaphycus seaweed farming development. Journal of Applied Phycology, 18(3–5), 241–249.
https://doi.org/10.1007/s10811-006-9023-0

169. Namukose, M., Msuya, F. E., Ferse, S. C. A., Slater, M. J., & Kunzmann, A. (2016). Growth performance of the sea cucumber Holothuria scabra and the seaweed Eucheuma denticulatum: integrated mariculture and effects on sediment organic characteristics. Aquaculture Environment Interactions, 8, 179–189.
https://doi.org/10.3354/aei00172

170. Narayanakumar, R., & Krishnan, M. (2011). Seaweed mariculture: an economically viable alternate livelihood option (ALO) for fishers. Indian Journal of Fisheries, 58(1), 79–84.

171. Narayanakumar, R., & Krishnan, M. (2013). Socio-economic assessment of seaweed farmers in Tamil Nadu - A case study in Ramanathapuram District. Indian Journal of Fisheries, 60(4), 51–57.

172. Navarrete, I. A., Kim, D. Y., Wilcox, C., Reed, D. C., Ginsburg, D. W., Dutton, J. M., Heidelberg, J., Raut, Y., & Wilcox, B. H. (2021). Effects of depth-cycling on nutrient uptake and biomass production in the giant kelp Macrocystis pyrifera. Renewable and Sustainable Energy Reviews, 141(110747), 110747.
https://doi.org/10.1016/j.rser.2021.110747

173. Ndobe, S., Yasir, I., Salanggon, A.-I. M., Wahyudi, D., Adel, Y. S., & Moore, A. M. (n.d.). Eucheumatoid seaweed farming under global change -Tomini Bay seaweed trial indicates Eucheuma denticulatum (spinosum) could contribute to climate adaptation 1. Com.Ro. Retrieved January 26, 2022, from

174. Neori, A. (2008). Essential role of seaweed cultivation in integrated multi-trophic aquaculture farms for global expansion of mariculture: an analysis. Journal of Applied Phycology, 20(5), 567–570.
https://doi.org/10.1007/s10811-007-9206-3

175. Neori, A., Bronfman, Y., van Rijn, J., Guttman, L., Krupnik, N., Shpigel, M., Samocha, T. M., Davis, D. A., Qiu, X., Abelin, P., & Israel, Á. (2020). The suitability of Ulva fasciata, Ulva compressa, and Hypnea musciformis for production in an outdoor spray cultivation system, with respect to biomass yield and protein content. Journal of Applied Phycology, 32(5), 3183–3197.
https://doi.org/10.1007/s10811-020-02130-3

176. Nogueira, M. C. F., & Henriques, M. B. (2020). Large-scale versus family-sized system production: economic feasibility of cultivating Kappaphycus alvarezii along the southeastern coast of Brazil. Journal of Applied Phycology, 32(3), 1893–1905.
https://doi.org/10.1007/s10811-020-02107-2

177. Nor, A. M., Gray, T. S., Caldwell, G. S., & Stead, S. M. (2020). A value chain analysis of Malaysia's seaweed industry. Journal of Applied Phycology, 32(4), 2161–2171.
https://doi.org/10.1007/s10811-019-02004-3

178. Nuryadi, A. M., La, S., Rianda, L., & Bafadal, A. (2019). A model for developing seaweed agribusiness in South Konawe, Southeast Sulawesi, Indonesia. Aquaculture, Aquarium, Conservation & Legislation Bioflux, 12(5), 1718-1725

179. Nwoba, E. G., Moheimani, N. R., Ubi, B. E., Ogbonna, J. C., Vadiveloo, A., Pluske, J. R., & Huisman, J. M. (2017). Macroalgae culture to treat anaerobic digestion piggery effluent (ADPE). Bioresource Technology, 227, 15–23.
https://doi.org/10.1016/j.biortech.2016.12.044

180. Oyarzo, S., Ávila, M., Alvear, P., Remonsellez, J. P., Contreras-Porcia, L., & Bulboa, C. (2021). Secondary attachment disc of edible seaweed Chondracanthus chamissoi (Rhodophyta, Gigartinales): Establishment of permanent thalli stock. Aquaculture (Amsterdam, Netherlands), 530(735954), 735954.
https://doi.org/10.1016/j.aquaculture.2020.735954

181. Padhi, S., Swain, P. K., Behura, S. K., Baidya, S., Behera, S. K., & Panigrahy, M. R. (2011). Cultivation of Gracilaria verrucosa (Huds) Papenfuss in Chilika Lake for livelihood generation in coastal areas of Orissa State. Journal of Applied Phycology, 23(2), 151–155.
https://doi.org/10.1007/s10811-010-9592-9

182. Pang, S. J., Xiao, T., & Bao, Y. (2006). Dynamic changes of total bacteria and Vibrio in an integrated seaweed–abalone culture system. Aquaculture (Amsterdam, Netherlands), 252(2–4), 289–297.
https://doi.org/10.1016/j.aquaculture.2005.06.050

183. Parakkasi, P., Rani, C., Syam, R., Zainuddin, & Achmad, M. (2020). Growth response and quality of seaweed Kappaphycus alvarezii cultivated in various coastal ecosystems in the waters of West Sulawesi, Indonesia. Aquaculture, Aquarium, Conservation & Legislation Bioflux, 13(2), 627–639.

184. Parakkasi, P., Syamsuddin, R., Haris, A., & Rani, C. (2020). Shading effect of seaweed farming on the growth and health of the corals Porites cylindrica and Acropora formosa. Aquaculture, Aquarium, Conservation & Legislation Bioflux, 13(3), 1650-1664.

185. Parenrengi, A., Dworjanyn, S., Syah, R., Pongmasak, P. R., & Fahrur, M. (2020). Strain selection for growth enhancement of wild and cultivated eucheumatoid seaweed species in Indonesia. Sains Malaysiana, 49(10), 2453–2464.
https://doi.org/10.17576/jsm-2020-4910-11

186. Peña-Rodríguez, A., Magallón-Barajas, F. J., Cruz-Suárez, L. E., Elizondo-González, R., & Moll, B. (2017). Effects of stocking density on the performance of brown shrimp Farfantepenaeus californiensis co-cultured with the green seaweed Ulva clathrata. Aquaculture Research, 48(6), 2803–2811.
https://doi.org/10.1111/are.13114

187. Pereira, S. A., Kimpara, J. M., & Valenti, W. C. (2021). Sustainability of the seaweed Hypnea pseudomusciformis farming in the tropical Southwestern Atlantic. Ecological Indicators, 121(107101), 107101.
https://doi.org/10.1016/j.ecolind.2020.107101

188. Periyasamy, C., Anantharaman, P., & Balasubramanian, T. (2014). Social upliftment of coastal fisher women through seaweed (Kappaphycus alvarezii (Doty) Doty) farming in Tamil Nadu, India. Journal of Applied Phycology, 26(2), 775–781.
https://doi.org/10.1007/s10811-013-0228-8

189. Peteiro, C. F. (2012). Observations on fish grazing of the cultured kelps Undaria pinnatifida and Saccharina latissima (Phaeophyceae, Laminariales) in Spanish Atlantic waters. Aquaculture, Aquarium, Conservation & Legislation Bioflux, 5(4), 189–196.

190. Peteiro, C., & Freire, Ó. (2011). Effect of water motion on the cultivation of the commercial seaweed Undaria pinnatifida in a coastal bay of Galicia, Northwest Spain. Aquaculture (Amsterdam, Netherlands), 314(1–4), 269–276.
https://doi.org/10.1016/j.aquaculture.2011.02.009

191. Peteiro, C., & Freire, Ó. (2013). Epiphytism on blades of the edible kelps Undaria pinnatifida and Saccharina latissima farmed under different abiotic conditions: Epiphytism on kelps farmed. Journal of the World Aquaculture Society, 44(5), 706–715.
https://doi.org/10.1111/jwas.12065

192. Phang, S.M., Keng, F. S.L., Singh, P.K. M., Lim, Y.K., Abd Rahman, N., Leedham, E. C., Robinson, A.D., R.P. Harris, N., A. Pyle, J., & Turges, W.T. (2015). Can seaweed farming in the tropics contribute to climate change through emission of short-lived halocarbons? Malaysian Journal of Science Series B, 34(1), 8–19.
https://doi.org/10.22452/mjs.vol34no1.2

193. Phang, S.M., Yeong, H.Y., Hussin, H., Lim, P.E., You, H.C., & Juan, J.C. (2017). Techno-economics of seaweed farming along the coasts of Kelantan, east coast peninsular Malaysia. Malaysian Journal of Science Series B, 36(2), 84–102.
https://doi.org/10.22452/mjs.vol36no2.4

194. Philippsen, A., Wild, P., & Rowe, A. (2014). Energy input, carbon intensity and cost for ethanol produced from farmed seaweed. Renewable and Sustainable Energy Reviews, 38, 609–623.
https://doi.org/10.1016/j.rser.2014.06.010

195. Poeloengasih, C. D., Bardant, T. B., Rosyida, V. T., Maryana, R., & Wahono, S. K. (2014). Coastal community empowerment in processing Kappaphycus alvarezii: a case study in Ceningan Island, Bali, Indonesia. Journal of Applied Phycology, 26(3), 1539–1546.
https://doi.org/10.1007/s10811-013-0153-x

196. Préat, N., De Troch, M., van Leeuwen, S., Taelman, S. E., De Meester, S., Allais, F., & Dewulf, J. (2018). Development of potential yield loss indicators to assess the effect of seaweed farming on fish landings. Algal Research, 35, 194–205.
https://doi.org/10.1016/j.algal.2018.08.030

197. Radulovich, R., Umanzor, S., Cabrera, R., & Mata, R. (2015). Tropical seaweeds for human food, their cultivation and its effect on biodiversity enrichment. Aquaculture (Amsterdam, Netherlands), 436, 40–46.
https://doi.org/10.1016/j.aquaculture.2014.10.032

198. Rameshkumar, S., & Rajaram, R. (2017). Experimental cultivation of invasive seaweed Kappaphycus alvarezii (Doty) Doty with assessment of macro and meiobenthos diversity from Tuticorin coast, Southeast coast of India. Regional Studies in Marine Science, 9, 117–125.
https://doi.org/10.1016/j.rsma.2016.12.002

199. Rani, S., Ahmed, M. K., Xiongzhi, X., Yuhuan, J., Keliang, C., & Islam, M. M. (2020). Economic valuation and conservation, restoration & management strategies of Saint Martin's coral island, Bangladesh. Ocean & Coastal Management, 183(105024).
https://doi.org/10.1016/j.ocecoaman.2019.105024

200. Revilla-Lovano, S., Sandoval-Gil, J. M., Zertuche-González, J. A., Belando-Torrentes, M. D., Bernardeau-Esteller, J., Rangel-Mendoza, L. K., Ferreira-Arrieta, A., Guzmán-Calderón, J. M., Camacho-Ibar, V. F., Muñiz-Salazar, R., & Ávila-López, M. C. (2021). Physiological responses and productivity of the seaweed Ulva ohnoi (Chlorophyta) under changing cultivation conditions in pilot large land-based ponds. Algal Research, 56(102316),
https://doi.org/10.1016/j.algal.2021.102316

201. Roberts, D. A., Paul, N. A., Dworjanyn, S. A., Hu, Y., Bird, M. I., & de Nys, R. (2015). Gracilaria waste biomass (sampah rumput laut) as a bioresource for selenium biosorption. Journal of Applied Phycology, 27(1), 611–620.
https://doi.org/10.1007/s10811-014-0346-y

202. Robertson-Andersson, D. V., Potgieter, M., Hansen, J., Bolton, J. J., Troell, M., Anderson, R. J., Halling, C., & Probyn, T. (2008). Integrated seaweed cultivation on an abalone farm in South Africa. Journal of Applied Phycology, 20(5), 579–595.
https://doi.org/10.1007/s10811-007-9239-7

203. Rößner, Y., Krost, P., & Schulz, C. (2014). Increasing seaweed crop yields through organic fertilisation at the nursery stage. Journal of Applied Phycology, 26(2), 753–762.
https://doi.org/10.1007/s10811-014-0269-7

204. Salayo, N. D., Perez, M. L., Garces, L. R., & Pido, M. D. (2012). Mariculture development and livelihood diversification in the Philippines. Marine Policy, 36(4), 867–881.
https://doi.org/10.1016/j.marpol.2011.12.003

205. Salazar, C., Jaime, M., & Quiroga, M. (2021). Transition patterns of fishermen and land farmers into small-scale seaweed aquaculture: The role of risk and time preferences. Marine Resource Economics, 36(3), 269–288.
https://doi.org/10.1086/714417

206. Salles, J. P., Scherner, F., Yoshimura, C. Y., Fanganiello, M., Bouzon, Z. L., & Horta, P. A. (2010). Cultivation of native seaweed Gracilaria domingensis (Rhodophyta) in Southern Brazil. Brazilian Archives of Biology and Technology, 53(3), 633–640.
https://doi.org/10.1590/S1516-89132010000300018

207. Sánchez-Romero, A., Miranda-Baeza, A., Rivas-Vega, M. E., López-Elías, J. A., Martínez-Córdova, L. R., & Tejeda-Mansir, A. (2016). Development of a model to simulate nitrogen dynamics in an integrated shrimp-macroalgae culture system with zero water exchange: Model of nitrogen dynamics in an integrated culture. Journal of the World Aquaculture Society, 47(1), 129–138.
https://doi.org/10.1111/jwas.12242

208. Sanderson, J. C., Dring, M. J., Davidson, K., & Kelly, M. S. (2012). Culture, yield and bioremediation potential of Palmaria palmata (Linnaeus) Weber & Mohr and Saccharina latissima (Linnaeus) C.E. Lane, C. Mayes, Druehl & G.W. Saunders adjacent to fish farm cages in northwest Scotland. Aquaculture, 354–355, 128–135.
https://doi.org/10.1016/j.aquaculture.2012.03.019

209. Santos, A. A., Brazil, S., Alves, A., Dorow, R., Araújo, L. A., & Hayashi, L. (2018). Socioeconomic analysis of the seaweed Kappaphycus alvarezii and mollusks (Crassostrea gigas and Perna perna) farming in Santa Catarina State, Southern Brazil. Custos e Agronegócios, 14(3), 443-472.

210. Sarkar, S., Rekha, P. N., Balasubramanian, C. P., & Ambasankar, K. (2019). Bioremediation Potential of the Brackishwater macroalga Gracilaria tenuistipitata (Rhodophyta) co-cultured with Pacific white shrimp Penaeus vannamei (Boone). Journal of Coastal Research, 86(sp1), 248.
https://doi.org/10.2112/si86-036.1

211. Sarkar, S., Rekha, P. N., Biswas, G., Ghoshal, T. K., Ambasankar, K., & Balasubramanian, C. P. (2019). Culture potential of the seaweed, Gracilaria tenuistipitata (Rhodophyta) in brackishwater tide fed pond system of sundarban, India. Journal of Coastal Research, 86(sp1), 258-262.
https://doi.org/10.2112/si86-038.1

212. Seghetta, M., Hou, X., Bastianoni, S., Bjerre, A.-B., & Thomsen, M. (2016). Life cycle assessment of macroalgal biorefinery for the production of ethanol, proteins and fertilizers – A step towards a regenerative bioeconomy. Journal of Cleaner Production, 137, 1158–1169.
https://doi.org/10.1016/j.jclepro.2016.07.195

213. Seghetta, M., Marchi, M., Thomsen, M., Bjerre, A.-B., & Bastianoni, S. (2016). Modelling biogenic carbon flow in a macroalgal biorefinery system. Algal Research, 18, 144–155.
https://doi.org/10.1016/j.algal.2016.05.030

214. Seghetta, M., Romeo, D., D'Este, M., Alvarado-Morales, M., Angelidaki, I., Bastianoni, S., & Thomsen, M. (2017). Seaweed as innovative feedstock for energy and feed – Evaluating the impacts through a Life Cycle Assessment. Journal of Cleaner Production, 150, 1–15.
https://doi.org/10.1016/j.jclepro.2017.02.022

215. Seghetta, M., Tørring, D., Bruhn, A., & Thomsen, M. (2016). Bioextraction potential of seaweed in Denmark — An instrument for circular nutrient management. The Science of the Total Environment, 563–564, 513–529.
https://doi.org/10.1016/j.scitotenv.2016.04.010

216. Semedi, B., da Costa, D. K., & Mahmudi, M. (2016). Feasibility study of seaweed (Kappaphycus alvarezii) mariculture using Geographic Information System in Hading Bay, East Flores Indonesia. Nature Environment and Pollution Technology, 15(4), 1347.

217. Setyawidati, N., Liabot, P. O., Perrot, T., Radiarta, N., Deslandes, E., Bourgougnon, N., Rossi, N., & Stiger-Pouvreau, V. (2017). In situ variability of carrageenan content and biomass in the cultivated red macroalga Kappaphycus alvarezii with an estimation of its carrageenan stock at the scale of the Malasoro Bay (Indonesia) using satellite image processing. Journal of Applied Phycology, 29(5), 2307–2321. h
ttps://doi.org/10.1007/s10811-017-1200-9

218. Shan, T., Li, Q., Wang, X., Su, L., & Pang, S. (2019). Assessment of the genetic connectivity between farmed populations on a typical kelp farm and adjacent spontaneous populations of Saccharina japonica (Phaeophyceae, Laminariales) in China. Frontiers in Marine Science, 6.
https://doi.org/10.3389/fmars.2019.00494

219. Shi, X., Qi, M., Tang, H., & Han, X. (2015). Spatial and temporal nutrient variations in the Yellow Sea and their effects on Ulva prolifera blooms. Estuarine, Coastal and Shelf Science, 163, 36–43.
https://doi.org/10.1016/j.ecss.2015.02.007

220. Sievanen, L., Crawford, B., Pollnac, R., & Lowe, C. (2005). Weeding through assumptions of livelihood approaches in ICM: Seaweed farming in the Philippines and Indonesia. Ocean & Coastal Management, 48(3–6), 297–313.
https://doi.org/10.1016/j.ocecoaman.2005.04.015

221. Smit, A. J., Fourie, A. M., Robertson, B. L., & du Preez, D. R. (2003). Control of the herbivorous isopod, Paridotea reticulata, in Gracilaria gracilis tank cultures. Aquaculture (Amsterdam, Netherlands), 217(1–4), 385–393.
https://doi.org/10.1016/s0044-8486(02)00412-x

222. Söderqvist, T., Bas, B., de Bel, M., Boon, A., Elginoz, N., Garção, R., Giannakis, E., Giannouli, A., Koundouri, P., Moussoulides, A., Norrman, J., Rosén, L., Schouten, J.-J., Stuiver, M., Tsani, S., Xepapadeas, P., & Xepapadeas, A. (2017). Socio-economic analysis of a selected multi-use offshore site in the North Sea. In The Ocean of Tomorrow (pp. 43–67). Springer International Publishing.

223. Soma, K., van den Burg, S. W. K., Selnes, T., & van der Heide, C. M. (2019). Assessing social innovation across offshore sectors in the Dutch North Sea. Ocean & Coastal Management, 167, 42–51.
https://doi.org/10.1016/j.ocecoaman.2018.10.003

224. Sondak, C. F. A., Ang, P. O., Jr, Beardall, J., Bellgrove, A., Boo, S. M., Gerung, G. S., Hepburn, C. D., Hong, D. D., Hu, Z., Kawai, H., Largo, D., Lee, J. A., Lim, P.-E., Mayakun, J., Nelson, W. A., Oak, J. H., Phang, S.-M., Sahoo, D., Peerapornpis, Y., … Chung, I. K. (2017). Carbon dioxide mitigation potential of seaweed aquaculture beds (SABs). Journal of Applied Phycology, 29(5), 2363–2373.
https://doi.org/10.1007/s10811-016-1022-1

225. Song, J. M., Li, X. G., Yuan, H. M., Zheng, G. X., & Yang, Y. F. (2008). Carbon fixed by phytoplankton and cultured algae in China coastal seas. Acta Ecol. Sin, 28(2), 551-558.

226. Song, W., Jiang, M., Wang, Z., Wang, H., Zhang, X., & Fu, M. (2018). Source of propagules of the fouling green macroalgae in the Subei Shoal, China. Hai Yang Xue Bao. Acta Oceanologica Sinica, 37(4), 102–108.
https://doi.org/10.1007/s13131-018-1169-5

227. Steenbergen, D. J., Marlessy, C., & Holle, E. (2017). Effects of rapid livelihood transitions: Examining local co-developed change following a seaweed farming boom. Marine Policy, 82, 216–223.
https://doi.org/10.1016/j.marpol.2017.03.026

228. Suyo, J. G. B., Le Masson, V., Shaxson, L., Luhan, M. R. J., & Hurtado, A. Q. (2020). A social network analysis of the Philippine seaweed farming industry: Unravelling the web. Marine Policy, 118(104007), 104007.
https://doi.org/10.1016/j.marpol.2020.104007

229. Suyo, J. G. B., Le Masson, V., Shaxson, L., Luhan, M. R. J., & Hurtado, A. Q. (2021). Navigating risks and uncertainties: Risk perceptions and risk management strategies in the Philippine seaweed industry. Marine Policy, 126(104408), 104408.
https://doi.org/10.1016/j.marpol.2021.104408

230. Tabassum, M. R., Xia, A., & Murphy, J. D. (2016). The effect of seasonal variation on biomethane production from seaweed and on application as a gaseous transport biofuel. Bioresource Technology, 209, 213–219.
https://doi.org/10.1016/j.biortech.2016.02.120

231. Tano, S. A., Halling, C., Lind, E., Buriyo, A., & Wikström, S. A. (2015). Extensive spread of farmed seaweeds causes a shift from native to non-native haplotypes in natural seaweed beds. Marine Biology, 162(10), 1983–1992.
https://doi.org/10.1007/s00227-015-2724-7

232. Thahir, H., Rombe, E., Ponisri, Vesakha, G., & Hadi, S. (2018). Analysis of internal risk management in Indonesian seaweed farming. International Journal of Engineering & Technology, 7(4.15), 200.
https://doi.org/10.14419/ijet.v7i4.15.21446

233. Thamrin, Y., Wahyu, A., Russeng, S. S., Wahyuni, A., & Hardianti, A. (2020). Ergonomics and musculoskeletal disorders among seaweed workers in Takalar Regency: A mixed method approach. Medicina Clínica Práctica, 3(sp1), 100110.
https://doi.org/10.1016/j.mcpsp.2020.100110

234. Theuerkauf, S. J., Morris, J. A., Jr, Waters, T. J., Wickliffe, L. C., Alleway, H. K., & Jones, R. C. (2019). A global spatial analysis reveals where marine aquaculture can benefit nature and people. PloS One, 14(10), e0222282.
https://doi.org/10.1371/journal.pone.0222282

235. Thomas, J.B E., Ribeiro, M.S., Potting, J., Cervin, G., Nylund, G.M., Olsson, J., Albers, E., Undeland, I., Pavia, H., & Gröndahl, F. (2021). A comparative environmental life cycle assessment of hatchery, cultivation, and preservation of the kelp Saccharina latissima. ICES Journal of Marine Science: Journal Du Conseil, 78(1), 451–467.
🔗 https://doi.org/10.1093/icesjms/fsaa112

236. Thomas, J.B.E., Ramos, F.S., & Gröndahl, F. (2019). Identifying suitable sites for macroalgae cultivation on the Swedish west coast. Coastal Management: An International Journal of Marine Environment, Resources, Law, and Society, 47(1), 88–106.
🔗 https://doi.org/10.1080/08920753.2019.1540906

237. Titlyanov, E. A., & Titlyanova, T. V. (2010). Seaweed cultivation: methods and problems. Russian Journal of Marine Biology, 36(4), 227-242.

238. Vadiveloo, A., Nwoba, E. G., & Moheimani, N. R. (2019). Viability of combining microalgae and macroalgae cultures for treating anaerobically digested piggery effluent. Journal of Environmental Sciences (China), 82, 132–144.
🔗 https://doi.org/10.1016/j.jes.2019.03.003

239. van den Burg, S. W. K., Röckmann, C., Banach, J. L., & van Hoof, L. (2020). Governing risks of multi-use: Seaweed aquaculture at offshore wind farms. Frontiers in Marine Science, 7.
🔗 https://doi.org/10.3389/fmars.2020.00060

240. van den Burg, S. W. K., van Duijn, A. P., Bartelings, H., van Krimpen, M. M., & Poelman, M. (2016). The economic feasibility of seaweed production in the North Sea. Aquaculture Economics & Management, 20(3), 235–252.
🔗 https://doi.org/10.1080/13657305.2016.1177859

241. van der Molen, J., Ruardij, P., Mooney, K., Kerrison, P., O'Connor, N. E., Gorman, E., Timmermans, K., Wright, S., Kelly, M., Hughes, A. D., & Capuzzo, E. (2018). Modelling potential production of macroalgae farms in UK and Dutch coastal waters. Biogeosciences, 15(4), 1123–1147.
🔗 https://doi.org/10.5194/bg-15-1123-2018

242. van Oirschot, R., Thomas, J.-B. E., Gröndahl, F., Fortuin, K. P. J., Brandenburg, W., & Potting, J. (2017). Explorative environmental life cycle assessment for system design of seaweed cultivation and drying. Algal Research, 27, 43–54.
🔗 https://doi.org/10.1016/j.algal.2017.07.025

243. Varela, D. A., Hernríquez, L. A., Fernández, P. A., Leal, P., Hernández-González, M. C., Figueroa, F. L., & Buschmann, A. H. (2018). Photosynthesis and nitrogen uptake of the giant kelp Macrocystis pyrifera (Ochrophyta) grown close to salmon farms. Marine Environmental Research, 135, 93–102.
🔗 https://doi.org/10.1016/j.marenvres.2018.02.002

244. Villanueva, R.D., Montaño, M.N.E., & Romero, J.B. (2009). Iota-carrageenan from a newly farmed, rare variety of eucheumoid seaweed—"endong." Journal of Applied Phycology, 21(1), 27–30.
🔗 https://doi.org/10.1007/s10811-008-9356-y

245. Villanueva, R.D., Romero, J.B., Montaño, M.N.E., & de la Peña, P.O. (2011). Harvest optimization of four Kappaphycus species from the Philippines. Biomass & Bioenergy, 35(3), 1311–1316.
🔗 https://doi.org/10.1016/j.biombioe.2010.12.044

246. Visch, W., Kononets, M., Hall, P.O.J., Nylund, G.M., & Pavia, H. (2020). Environmental impact of kelp (Saccharina l atissima) aquaculture. Marine Pollution Bulletin, 155, 110962.
🔗 https://doi.org/10.1016/j.marpolbul.2020.110962

247. Wallner-Hahn, S., & de la Torre-Castro, M. (2017). Early steps for successful management in small-scale fisheries: An analysis of fishers', managers' and scientists' opinions preceding implementation. Marine Pollution Bulletin, 134, 186–196.
🔗 https://doi.org/10.1016/j.marpolbul.2017.07.058

248. Walls, A. M., Edwards, M. D., Firth, L. B., & Johnson, M. P. (2017). Successional changes of epibiont fouling communities of the cultivated kelp Alaria esculenta: predictability and influences. Aquaculture Environment Interactions, 9, 57–71.
🔗 https://doi.org/10.3354/aei00215

249. Walls, A. M., Edwards, M. D., Firth, L. B., & Johnson, M. P. (2019). Ecological priming of artificial aquaculture structures: kelp farms as an example. Journal of the Marine Biological Association of the United Kingdom. Marine Biological Association of the United Kingdom, 99(4), 729–740.
🔗 https://doi.org/10.1017/s0025315418000723

250. Walls, A. M., Kennedy, R., Edwards, M. D., & Johnson, M. P. (2017). Impact of kelp cultivation on the Ecological Status of benthic habitats and Zostera marina seagrass biomass. Marine Pollution Bulletin, 123(1–2), 19–27.
🔗 https://doi.org/10.1016/j.marpolbul.2017.07.048

251. Walls, A. M., Kennedy, R., Fitzgerald, R. D., Blight, A. J., Johnson, M. P., & Edwards, M. D. (2016). Potential novel habitat created by holdfasts from cultivated Laminaria digitata: assessing the macroinvertebrate assemblages. Aquaculture Environment Interactions, 8, 157–169.
🔗 https://doi.org/10.3354/aei00170

252. Wang, Q., Luan, L.-L., Chen, L.-D., Yuan, D.-N., Liu, S., Hwang, J.-S., & Yang, Y.-F. (2016). Recruitment from an egg bank into the plankton in Baisha Bay, a mariculture base in Southern China. Estuarine, Coastal and Shelf Science, 181, 312–318.
🔗 https://doi.org/10.1016/j.ecss.2016.08.040

253. Wang, Z., Xiao, J., Fan, S., Li, Y., Liu, X., & Liu, D. (2015). Who made the world's largest green tide in China?-an integrated study on the initiation and early development of the green tide in Yellow Sea: Green tide in Yellow Sea of China. Limnology and Oceanography, 60(4), 1105–1117.
🔗 https://doi.org/10.1002/lno.10083

254. Whiting, J. M., Wang, T., Yang, Z., Huesemann, M. H., Wolfram, P. J., Mumford, T. F., & Righi, D. (2020). Simulating the trajectory and biomass growth of free-floating macroalgal cultivation platforms along the U.S. west coast. Journal of Marine Science and Engineering, 8(11), 938.
https://doi.org/10.3390/jmse8110938

255. Wibowo, Y., Nafi, A., & Jawara, R. R. (2020). Effect of seed type and harvest time of seaweed (Eucheuma cottonii) on the quality of alkali treated cottonii. International Journal on Advanced Science, Engineering and Information Technology, 10(4), 1669.
https://doi.org/10.18517/ijaseit.10.4.11534

256. Wu, J., Zhang, H., Pan, Y., Krause-Jensen, D., He, Z., Fan, W., Xiao, X., Chung, I., Marbà, N., Serrano, O., Rivkin, R. B., Zheng, Y., Gu, J., Zhang, X., Zhang, Z., Zhao, P., Qiu, W., Chen, G., & Duarte, C. M. (2020). Opportunities for blue carbon strategies in China. Ocean & Coastal Management, 194, 105241.
https://doi.org/10.1016/j.ocecoaman.2020.105241

257. Xia, B., Cui, Y., Chen, B., Cui, Z., Qu, K., & Ma, F. (2014). Carbon and nitrogen isotopes analysis and sources of organic matter in surface sediments from the Sanggou Bay and its adjacent areas, China. Acta Oceanologica Sinica, 33(12), 48–57.
https://doi.org/10.1007/s13131-014-0574-7

258. Xiao, X., Agusti, S., Lin, F., Li, K., Pan, Y., Yu, Y., Zheng, Y., Wu, J., & Duarte, C. M. (2017). Nutrient removal from Chinese coastal waters by large-scale seaweed aquaculture. Scientific Reports, 7(1), 46613.
https://doi.org/10.1038/srep46613

259. Xiao, X., Agustí, S., Yu, Y., Huang, Y., Chen, W., Hu, J., Li, C., Li, K., Wei, F., Lu, Y., Xu, C., Chen, Z., Liu, S., Zeng, J., Wu, J., & Duarte, C. M. (2021). Seaweed farms provide refugia from ocean acidification. The Science of the Total Environment, 776, 145192.
https://doi.org/10.1016/j.scitotenv.2021.145192

260. Xie, X., He, Z., Hu, X., Yin, H., Liu, X., & Yang, Y. (2017). Large-scale seaweed cultivation diverges water and sediment microbial communities in the coast of Nan'ao Island, South China Sea. The Science of the Total Environment, 598, 97–108.
https://doi.org/10.1016/j.scitotenv.2017.03.233

261 Xing, Q., An, D., Zheng, X., Wei, Z., Wang, X., Li, L., Tian, L., & Chen, J. (2019). Monitoring seaweed aquaculture in the Yellow Sea with multiple sensors for managing the disaster of macroalgal blooms. Remote Sensing of Environment, 231, 111279.
https://doi.org/10.1016/j.rse.2019.111279

262. Xu, Q., Zhang, H., Ju, L., & Chen, M. (2014). Interannual variability of Ulva prolifera blooms in the Yellow Sea. International Journal of Remote Sensing, 35(11–12), 4099–4113.
https://doi.org/10.1080/01431161.2014.916052

263. Yan, C., McWilliams, J. C., & Chamecki, M. (2021). Generation of attached Langmuir circulations by a suspended macroalgal farm. Journal of Fluid Mechanics, 915(A76).
https://doi.org/10.1017/jfm.2021.111

264. Yang, Y., Liu, Q., Chai, Z., & Tang, Y. (2015). Inhibition of marine coastal bloom-forming phytoplankton by commercially cultivated Gracilaria lemaneiformis (Rhodophyta). Journal of Applied Phycology, 27(6), 2341–2352.
https://doi.org/10.1007/s10811-014-0486-0

265. Yang, Y.-F., Fei, X.-G., Song, J.-M., Hu, H.-Y., Wang, G.-C., & Chung, I. K. (2006). Growth of Gracilaria lemaneiformis under different cultivation conditions and its effects on nutrient removal in Chinese coastal waters. Aquaculture (Amsterdam, Netherlands), 254(1–4), 248–255.
https://doi.org/10.1016/j.aquaculture.2005.08.029

266. Ye, G., Jin, M., & Jia, S. (2018). Ecological service value evaluation of seaweed aquaculture in Zhejiang and Jiangsu Provinces. Journal of Fisheries of China, 42(8), 1254-1262.

267. Yong, Y. S., Yong, W. T. L., Thien, V. Y., Ng, S. E., Anton, A., & Yassir, S. (2015). Acclimatization of micropropagated Kappaphycus alvarezii (Doty) Doty ex Silva (Rhodophyta, Solieriaceae) in outdoor nursery system. Journal of Applied Phycology, 27(1), 413–419.
https://doi.org/10.1007/s10811-014-0289-3

268. Yoshimura, C. Y., Cunha, S. R., & Oliveira, E. C. (2006). Testing open-water cultivation techniques to Gracilaria domingensis (Rhodophyta, Gracilariales) in Santa Catarina, Brazil. Journal of Coastal Research, 1290–1293.

269. Zamroni, A., Laoubi, K., & Yamao, M. (2011). The development of seaweed farming as a sustainable coastal management method in Indonesia: an opportunities and constraints assessment. Sustainable Development and Planning V.

270. Zhang, A., Wen, X., Yan, H., He, X., Su, H., Tang, H., Jordan, R. W., Wang, Y., & Jiang, S. (2018). Response of microalgae to large-seaweed cultivation as revealed by particulate organic matter from an integrated aquaculture off Nan'ao Island, South China. Marine Pollution Bulletin, 133, 137–143.
https://doi.org/10.1016/j.marpolbul.2018.05.026

271. Zhang, J., Shi, J., Gao, S., Huo, Y., Cui, J., Shen, H., Liu, G., & He, P. (2019). Annual patterns of macroalgal blooms in the Yellow Sea during 2007-2017. PloS One, 14(1), e0210460.
https://doi.org/10.1371/journal.pone.0210460

272. Zhang, J., Zhao, P., Huo, Y., Yu, K., & He, P. (2017). The fast expansion of Pyropia aquaculture in "Sansha" regions should be mainly responsible for the Ulva blooms in Yellow Sea. Estuarine, Coastal and Shelf Science, 189, 58–65.
https://doi.org/10.1016/j.ecss.2017.03.011

273. Zhang, J., Hansen, P. K., Fang, J., Wang, W., & Jiang, Z. (2009). Assessment of the local environmental impact of intensive marine shellfish and seaweed farming—Application of the MOM system in the Sungo Bay, China. Aquaculture (Amsterdam, Netherlands), 287(3–4), 304–310.
https://doi.org/10.1016/j.aquaculture.2008.10.008

274. Zhang, J., Hansen, P. K., Wu, W., Liu, Y., Sun, K., Zhao, Y., & Li, Y. (2020). Sediment-focused environmental impact of long-term large- scale marine bivalve and seaweed farming in Sungo Bay, China. Aquaculture (Amsterdam, Netherlands), 528(735561), 735561.
https://doi.org/10.1016/j.aquaculture.2020.735561

275. Zhang, X., Uchiyama, Y., & Nakayama, A. (2019). On relaxation of the influences of treated sewage effluent on an adjacent seaweed farm in a tidal strait. Marine Pollution Bulletin, 144, 265–274.
https://doi.org/10.1016/j.marpolbul.2019.04.050

276. Zhao, X. B., Pang, S. J., Liu, F., Shan, T. F., Li, J., Gao, S. Q., & Kim, H. G. (2016). Intraspecific crossing of Saccharina japonica using distantly related unialgal gametophytes benefits kelp farming by improving blade quality and productivity at Sanggou Bay, China. Journal of Applied Phycology, 28(1), 449–455.
https://doi.org/10.1007/s10811-015-0597-2

277. Zheng, Y., Jin, R., Zhang, X., Wang, Q., & Wu, J. (2019). The considerable environmental benefits of seaweed aquaculture in China. Stochastic Environmental Research and Risk Assessment: Research Journal, 33(4–6), 1203–1221.
https://doi.org/10.1007/s00477-019-01685-z

278. Zhou, Y., Yang, H., Hu, H., Liu, Y., Mao, Y., Zhou, H., Xu, X., & Zhang, F. (2006). Bioremediation potential of the macroalga Gracilaria lemaneiformis (Rhodophyta) integrated into fed fish culture in coastal waters of north China. Aquaculture (Amsterdam, Netherlands), 252(2–4), 264–276.
https://doi.org/10.1016/j.aquaculture.2005.06.046

279. Zuniga-Jara, S., & Contreras, C. (2020). An economic valuation of the commercial cultivation of Agarophyton chilensis in northern Chile. Journal of Applied Phycology, 32(5), 3233–3242.
https://doi.org/10.1007/s10811-020-02165-6

280. Zuniga-Jara, S., & Soria-Barreto, K. (2018). Prospects for the commercial cultivation of macroalgae in northern Chile: the case of Chondracanthus chamissoi and Lessonia trabeculata. Journal of Applied Phycology, 30(2), 1135–1147.
https://doi.org/10.1007/s10811-017-1298-9

ANNEXES

9. Annexes

9.1 Annex 1 – Work document of the Delphi Process

9.1.1 Questions sent to the experts for the first round of the Delphi Process

Dear Expert,
RE: Expert opinion requested to highlight knowledge gaps for enabling the upscaling macroalgal cultivation in European waters.

This questionnaire is part of ongoing work carried out under the framework of the EKLIPSE Macroalgae expert group. This group was formed in February 2021 as a response to a request made to Eklipse by the European Commission's Directorate General for Maritime Affairs & Fisheries, Unit for Maritime Innovation, Marine Knowledge and Investment (DG MARE), following Eklipse's fifth call for requests (CfR.5/2020). The request was: What are the knowledge gaps to be addressed before harvesting the potential of macroalgae culture in providing climate-related and other ecosystem services (i.e., coastal protection; nutrient recycling; lower impact food; lower impact material; etc.) especially at larger scales?

For the purpose of this work, we consider the definition of Ecosystem Services as accepted by CICES (available from www.cices.eu).

With a strong focus on the identification of knowledge gaps on ecosystem services and macro-algae cultivation, this Eklipse exercise will take into account qualitative and quantitative data. Such assessment is needed to critically assess the potential of upscaling macroalgae culture to serve as a solution to mitigate climate change, enhance coastal biodiversity and provide sustainable ecosystem services. Eklipse results are expected to inform future macroalgae research and Commission activities, through the identification of knowledge gaps.
You are receiving this information because you were selected as an expert and/or key stakeholder and we value your opinions on this matter. We kindly ask you to reply to the questions below within 7 days. There is no word limit for your replies, but we do ask you to be as specific as possible. There is no need to elaborate your answers with justifications (such as references). We estimate that the questionnaire will take no longer than 20 minutes to complete.

Please note that this is the first round of questions for this Delphi process and we will be very grateful if you would be happy for us to contact you again in a few weeks for further rounds. These next rounds may, for instance, ask you to rank the answers given during the first round and secondly ask you to review your initial ranking based on the overall responses provided.

To standardize the language of marine aquaculture, we propose three site categories: "nearshore sheltered", "nearshore exposed" and "offshore" sites, according to Bak et al. (2020). These categories are dependent on two site attributes: "water depth" and "distance to shore". The offshore site category is reserved for sites with a distance to shore of ≥3 NM; the nearshore exposed are sites with a water depth ≥50 m yet <3 NM from shore; finally, the nearshore sheltered sites are those with a water depth <50 m and <3 NM from shore.
For the following questions please specify whether your answers are applicable to land based cultivation, transitional (e.g., estuaries) or marine waters (e.g., near shore sheltered, near shore exposed, off shore) or common to some or all of these.

1 – Please list the most important Ecosystem Goods and Services (ES) that macroalgae cultivation can provide.

2 – What are the knowledge gaps on macroalgae cultivation (e.g., processing and marketing) that would need to be addressed in order to upscale it and enhance its delivery of ES? a

3 – What are, in your opinion, the main constraints (e.g., technological, political, economic, legal, social, environmental) that need to be resolved before significantly upscaling macroalgae culture?

4 – What negative impacts or trade-offs may upscaling macro-algae cultivation lead to, particularly when it comes to ES?

Background assessment of the participants

1 – **Which of the following sectors do you consider most relevant to your experience?**

A Academic/research

B Industry (e.g., producer, processing, marketing and sales)

C NGO (e.g., environmental)

D Other marine organizations (e.g., political entities, professional associations, other not included elsewhere)

2 – **If you belong to the Academic or Industry sector, on which aspect do you focus your work:**

☐ Macroalgae hatchery/nursery ☐ Macroalgae processing

☐ Macroalgae cultivation ☐ Marketing and sales

3 – **Is your work experience focused on one country or region? If yes, please specify.**

☐ Asia and the Pacific ....

☐ Europe ....

☐ Latin America and the Caribbean ....

☐ Near East ....

☐ North America ....

4 – **Is your work experience particularly focused on a macroalgae species or group of species? If so, please specify.**

5 – **Is your work experience focused on a specific site category from the following: land-based cultivation, transitional (e.g., estuaries) or marine waters (near shore sheltered, near shore exposed, off shore)**

6 – **How many years of work experience do you consider yourself to have?**

☐ 1 – 5 years ☐ 6-20 years ☐ more than 20 years

9.1.2 Questions sent to the experts for the second round of the Delphi Process.

Dear Expert,

RE: Expert opinion requested to highlight knowledge gaps for enabling the upscaling of macroalgal cultivation
First of all, we thank you once again for the time you spent in the previous round of this process. Your contributions are extremely important for our work group.
As explained in our previous message, as a follow up of the 1st round of the Delphi process, we now ask your contribution for the second and final round. In this stage we have only four tasks. Essentially you are asked to rank the 5 most important options listed, which are derived from all the answers obtained in the previous round.

1 – From the list of Ecosystem Goods and Services (ES) presented below, please select the 5 that are most important for you and rank them from 1 to 5, where 1 is the most important and 5 is the least important of the ones selected. This list was obtained from the answers in the previous round.

☐ Macroalgae grown for food (including hydrocolloids)
☐ Macroalgae grown for feed
☐ Macroalgae grown as a source of energy
☐ Regulation of Water quality (including eutrophication, biomitigation, bioremediation)
☐ Carbon sequestration/storage/accumulation by macroalgae
☐ Climate regulation (CO2, carbon cycle, DMS, OTHER)
☐ Coastal protection (erosion, wave reduction, flood control)
☐ Maintaining nursery populations and habitats (including gene pool protection)
☐ Pest and disease control
☐ Characteristics of living systems that enable education and training
☐ Elements of living systems used for recreation and tourism

2 - From the list of knowledge gaps presented below, please select the 5 that are most important to you and rank them from 1 to 5 where 1 is the most important and 5 is the least important of the ones selected. If you include a category with subcategories please rank also those.
Note that these are the knowledge gaps on macroalgae cultivation that would need to be addressed in order to upscale it and enhance its ES, according to the answers from the previous round.

☐ **Environmental Data**
- Occurrence/impact of nuisance species
- Biodiversity impact
- Nutrient uptake/bioremediation

☐ **Farming Technologies**
- Ensure consistent production quality
- Strain improvement
- Technologies for further cultivation approaches
- Develop mechanization for seaweed farming

☐ **Technologies for macroalgae processing**

☐ **Data obtained from “real” macroalgae farming**
- Appropriate scale of production
- Appropriate spatial planning for farming sites

☐ **Market data**
- Adequate price
- Adequate value-chain connections
- Detailed market information

- ☐ Economic data
    - Information on valorization of Ecosystem Services
    - Appropriate business cases
- ☐ Politics
- ☐ Certification
    - Food Safety
    - CO2 footprint
    - Ecosystem provisioning
- ☐ Training

2.1 Please provide, in a concise manner, possible ways (tasks and/or key players) to address those knowledge gaps.

3 – From the list of negative impacts or trade-offs that macroalgae cultivation upscaling may lead to (identified in the previous round of questions) please select the 5 that you think are most severe and rank them from 1 to 5, where 1 is likely to be the most severe and 5 is the least severe of the ones selected.

- ☐ Conflict with other users/uses (at land or sea)
- ☐ Negative impacts on ecosystem biodiversity
- ☐ Aesthetics
- ☐ Mismatch in supply and demand of biomass
- ☐ Unknown environmental impacts (e.g. on deep sea, benthic and pelagic ecosystems)
- ☐ Over exploitation of the environment
- ☐ Shifts in seaweed genetic diversity
- ☐ Pollution (e.g. plastics)
- ☐ Water flow reduction
- ☐ Physical damage (e.g. damage to the sea floor resulting from the farming structures, anchors, stakes, etc.)

9.2 Annex 2 – Some examples of constraints provided by experts that participated in the first round of the Delphi questionnaire

SOME EXAMPLES OF SPECIFIC CONSTRAINTS IDENTIFIED BY THE DELPHI RESPONDENTS
"Legal aspect and a real seaweed sector being set in place - at present people compete while they should work together"
"Technological constraints: Farming technologies for off-shore cultivation including suitable cultivars and structures"
"Improved technologies for deployment, harvesting and processing."
"Economic: cost savings, revenue increase for niche markets like European cultivated macro algae; Proper legislation, removing obstacles and providing incentives"
"Social licence; political frameworks for development and permitting; R&D on potential uses, what are the markets"
"It is quite possible to have a significant impact on a system's carrying capacity with significant upscaling. We can calculate how big the impact is on nutrients and phytoplankton primary production. However, deciding what an acceptable level of extraction is, is difficult. It is a political choice and it requires insight in the knock-on effects on higher trophic levels."
"Valorising the effects to €; Find ways to get being paid for the service ■ Space: 1000 ton fish requires min. 100 ha seaweed farm to remediate 50 % of the nutrients. ■ Legislation with respect to seaweed farming ■ Certification and liability questions ■ New seaweed applications in food and feed need supportive legislation"
"Spatial planning and the licensing of farms."
"Address algae as future ressource and bring knowledge to consumers (knowledge transfer through marketing strategies); Enable for large-scale production from a legal-side; Develop fast downstream processing (or storing) of produced biomass"
"...ES of all marine and aquatic photoautotrophs must be considered in a holistic way ... macroalgae must not be handled as if they are the only organisms photosynthesizing in marine and aquatic ecosystems".
"This question can only be answered on a geographical basis. In East Asia, Europe and Southern Africa, you would get completely different answers. In East Asia, it has already been upscaled. In Europe production is limited by lack of markets (changing rapidly)."

9.3 Annex 3 – Overview of different categories used for classification of different articles selected in the QSR

N°	CATEGORY	SUBCATEGORIES	EXPLANATION
1	Species		Species or taxonomic group considered in the study.
2	Country		Country, countries or geographic region (e.g. North Atlantic coast of Europe) where the study was performed
3	Scale	NA/Local/Regional/Large/Global	Specify study scale choosing one of the options
4	Sector	NA	
		All	Non specified or seaweed aquaculture in a general sense
		None	Seaweed harvesting, seaweed as resource...
		Land-based cultivation	Cultivation of macroalgae on land.
		Transitional	Cultivation of macroalgae in estuarine or brackish waters.
		Near-shore, sheltered	Cultivation of macroalgae in marine waters <50 m water depth & <3 NM distance to shore.
		Near-shore, exposed	Cultivation of macroalgae in marine waters >50 m depth & <3 NM from shore.
		Offshore	>3 NM from shore.
5	PESTEL analysis	NA	
		Political	
		Economic	
		Social	
		Technical	
		Environmental	
		Legal	
6	Aquaculture type	NA	
		All	Non specified or seaweed aquaculture in a general sense.
		None	Seaweed harvesting, seaweed as resource...
		Land-based cultivation	Cultivation of macroalgae on land.
		Transitional	Cultivation of macroalgae in estuarine or brackish waters.
		Near-shore, sheltered	Cultivation of macroalgae in marine waters <50 m water depth & <3 NM distance to shore.
		Near-shore, exposed	cultivation of macroalgae in marine waters >50 m depth & <3 NM from shore.
		Offshore	>3 NM from shore.
7	Study protocol	NA	NA
		BACI	Studies considering a „Before-After-Control-Impact" design.
		Before-After	Studies considering conditions previous to the installation of seaweed aquaculture facilities.
		Control-Impact	Studies comparing natural communities and seaweed crops.
		Descriptive	Descriptive or observational studies with no comparisons with references.
		Other	Other studies not considering quantitative or qualitative analyses.

N°	CATEGORY	SUBCATEGORIES	EXPLANATION
		Modelling	Studies using models to assess or identify ecosystem services or disservices.
8	Farm size	N/A	not defined in the methodological part
		Pilot	Small-scale, experimental farm to test feasibility
		Small	e.g. family runned farms of villages
		Medium	e.g. larger farming activities but not as extended as covering bays, regions; or farms with < 50 lines (x 200 m; Campbell et al. 2019)
		Large	e.g. farming activities covering whole bays, regions, or large coastal areas; or farms with > 50 lines (x 200 m; Campbell et al. 2019)
9	Provisioning	NA	not defined in the methodological part
		Food	
		Hydrocolloids	
		Feed (specified)	
		Other (specified)	
10	Regulating and maintenance	NA	not defined in the methodological part
		Biological regulation (specified)	Alien species, biodiversity/genetic conservation, habitat provision, algal bloom regulation, other.
		Water quality	Eutrophication, biomitigation, bioremediation. Specified.
		Coastal protection	Erosion, wave reduction.
		Climate regulation (specified)	CO2, carbon cycle, DMS, other.
		Other (specified)	
11	Cultural	NA	
		Symbolic and esthetic	
		Recreation and tourism	
		Cognitive (specified)	Inspiration
		Scientific knowledge (specified)	e.g. Number of proposals/grants.
		Education/learning	
		Other (specified)	
12	Knowledge gaps		
13	Identified constraints		
14	Disservice/Negative Impacts/Trade-Offs		
15	Disservice comments		
16	Expert notes		
17	Specified		Additional information to different drop-down points, when required

9.4 Annex 4 – Overview of different types of constraints identified in the analysed literature

PESTEL	TYPE	DESCRIPTION
Study	Length	Insufficient study length
	Size	Small scale (spatial and temporal) experiment
	Stats	Correlational data, not evaluated data
Environmental	Data	Insufficient amount of environmental data
	Seasonality	Seasonal effects, e.g. during growing harvesting period
	Weather	Storms and extreme events
	Substrate	Effect of type and conditions of natural or artificial substrate
	Emission	CO2, Nutrients balance - footprint
	Nuisance species	Encrusting or epiphytic organisms affecting biomass quality or cultivation process; diseases
	Water conditions	Water quality and remediation processes and pollution load not sufficiently known
	Predator/grazer	Grazing on cultivated macroalgae
	Biological shift	Effects on taxa and communities adjacent to the seaweed farm
	Invasion	Introduction of invasive non-native species
Economical	Financiation	Unclear/unspecified financial viability, dependence on other lifestocks
	Market	Market and value chain elements
Technical	Nursery	Seedling, stock quality, new strains in cultivation
	Post-Harvest	Management and processes after harvesting
	Harvest	Timing, techniques etc. harvest-related
	Production	Amount of produced biomass, production speed
	Product quality	Quality of seaweed products
	Training	Training of people
	Technology	Development in technology
Political	ABS	Access benefit sharing
	Dependence	Close relation / connection to other activities, e.g. wind parks
	No support	No governance support
	Space	Use of space
	Awareness	Potential provision of ecosystem services
Social	Gender	Gender inequality observed
	Jobs	Jobs connected with seaweed aquaculture
	Stakeholder	Stakeholder perception

9.5 Annex 5 – Overview of different types of Knowledge Gaps identified in the analysed literature

PESTEL	TYPE	EXAMPLES
Environmental	Data	Uncertainty associated with modelling, need for more validated models, need for systematic data collection
	Seasonality	Observed seasonal/ inter-annual effects, e.g. growing/ harvesting period
	Weather	Observed effects of more severe weather events e.g. storms
	Substrate	Effect of present natural or artificial substrate (type, conditions), creation of novel habitats
	Emission/Absorption	CO2, Nutrients balance - food print, species dependent, Carbon footprint (using seaweed as terrestrial crop fertiliser), need for LCA for CO2 regarding bioethanol production, impact of emission of volatile halocarbons
	Nuisance species / dis-eases	Incrusting or epiphytising organisms affecting biomass quality or cultivation process, diseases, biofouling, HAB formation and mitigation measures, influence of environmental conditions
	Water quality	Water quality and remediation processes and pollution load not sufficiently known, nutrient inputs from terrestrial systems, cultivation in transitional waters
	Predator/grazer	Grazing on cultivated macroalgae vs epiphyte control, effect of grazing on production losses
	Introduced species	Introduced species, population etc. spreading in comparison to local types, maintenance and biosecurity
	Wider ecosystem effects	Effect of farms on coral reefs, phytoplankton communities, seagrass beds, fish assemblages/ landings, fish farms, water quality, potential overharvesting of wild stocks, microbial communities, impact of associated communities post-harvest, creation of novel habitats, effect of stocking density, persistence of ecosystem services when seaweed cultivated
	Genetic	Effect on native seagrass genetic diversity, relationship between native and wild populations, influence of geographical distance and habitat discontinuity
	Carrying capacity	Effect on carrying capacity of region
Economical	Financial	Financial viability, co-culture potential, sharing of ABS agreements
	LCA	Life Cycle Assessment for different products (e.g. biofuel, protein, liquid fertilisers) and culture environments (e.g. seawalls). Need to consider climate change in risk analysis
Technical	Nursery	Seedlings, reproductive life cycles, stock quality, new strains in cultivation, development of new strain markers, nutrient storage/ deficiencies on pre-deployment phase, optimal stocking densities in IMTA systems, new cultivars to improve nutrient uptake, role of microalgae unintentionally introduced into system. Optimisation of aeration regimes.
	Post-harvest	Management and processes after harvesting, e.g. way lengths, use of valuable pigments, biofuel production, downstream processing
	Hazards	In production process
	Harvest	Quality, timing, techniques etc. concerning the harvest, particularly when upscaling, stocking density

PESTEL	TYPE	EXAMPLES
	Production	Amount of produced biomass, production speed, use of new farming methods (e.g. rafts) and associated growth rates, life cycle emissions, attachment mechanisms, influence of depth on growth rates, influences on nitrate/ phosphate uptake/ limitations, monitoring of carrageenan content using satellites, biofiltration potential, optimum light exposure. Effects of low water movement. need for longer experimental periods. Need for larger size of experiments (spatial and temporal), N/P global uptakes. Offshore farm design. Optimisation of aeration regimes (as in Nursery section).
	Product quality	Greater knowledge on carrageenan chemistry
	Training	Seed selection criteria
	Technology	New technology - effectiveness, use of land/ sea based IMTA systems, new seeding techniques testing, new species, floating longlines, potential of secondary organisms in process. Energy saving processing (by-product extraction), improving growth in low nutrient environments, effectiveness of depth-cycling to increase nutrient availability/ prevent thermal stress, bioprospecting
Political	ABS	Access benefit sharing
	Dependence	Close relation/ connection to other topics, e.g. wind parks
	Support	Need to develop policies to guide markets
Social	Gender	Gender inequality observed, need for support mechanisms for access to information, resources, services, input to shaping risk assessments
	Jobs	Jobs connected with SA, creation of jobs for fishing communities
	Stakeholder	Stakeholder perception, acceptability, development strategies, site selection, impacts on communities, communication and Knowledge transfer
	Occupational Health	Farmer safety - issues and solutions
	Coping with climate change	Adaptive strategies for seaweed farming communities to cope with climate change
Legal	Governance	Governance (e.g. co-location of seaweed farms with offshore wind), spatial planning, biosecurity, international framework for biosecurity required, need to establish rules on verification of air-sea CO_2 flux and permanence of carbon storage, lack of policies specific to seaweeds (e.g. no list of specific diseases/ pathogens)
	Contaminant limits	Regulations on contaminant levels (e.g., bacteria)

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