Bridging the gap between policy and knowledge on biodiversity in Europe

Document of Work (DoW)
Macroalgae culture Request
February 2021

CONTENT

GENERAL INFORMATION

Original title: What is the state of knowledge regarding the potential of macro-algae culture in providing climate-related and other ecosystem services (i.e. coastal protection; nutrient recycling; lower impact food; lower impact material; etc.)? Are there specific knowledge gaps to be addressed before harvesting this potential?

This request was initially put to Eklipse following Eklipse's fifth call for requests (CfR.5/2020) by the European Commission's Directorate-General for Maritime Affairs & Fisheries, Unit for Maritime Innovation, Marine Knowledge and Investment (DG MARE).

Requesters: Zoi Konstantinou from DG Maritime Affairs & Fisheries, Unit for Maritime Innovation, Marine Knowledge and Investment (DG MARE).
Date request received: April/2020 (selection June)
Date of first meeting with requesters, Eklipse KCB and methods experts: 23rd July 2020
Expected deadline for deliverables: Having a first draft of the results by the first half of 2021 (ideally end of May/beginning of June) would be highly desirable, to support further actions related to the subject.
Due to Covid 19 and depending on the methods chosen it seems that results will be delayed from the desired schedule. Yet, the assessment of the questions set by the request are likely to be done in 2-3 methodological steps (see Section X). First results from Delphi process could be available within the original schedule, but the scoping of the literature to elaborate and verify findings of the Delphi will probably not be available by the beginning of 2021.

Revised deadline :

Timeline-2021

- Application deadline: 8th January
- Experts selected: 25th January
- Kick-off meeting: 22nd February
- 1st draft: 4th June ?
- Final draft: 31st August
- Final version: 15th September

In order to refine the request, the following scoping activities have been carried out:

a. Call for Knowledge in order to identify already existing work on the request;
b. Evaluation of the policy and stakeholder relevance via bilateral telephone interviews and email requests;
c. Call for knowledge to verify that the question / request has not been answered by existing knowledge (however, with very limited responses from expert communities)

This Document of Work (DoW) describes the results of the scoping activities as well as the background of the request and is the basis for the call for experts. It explores the existing knowledge in this area, who the main knowledge holders are, how the request relates to existing policy processes at the EU level, and identifies plausible and relevant programme of work and methodology for answering this request.

BACKGROUND AND CONTEXT OF THE CALL

Original request text

The potentials of macro-algae culture to provide a wide range of ecosystem services, climate-related and other, is widely discussed, especially in the framework of the imminent actions necessary for climate-change adaptation and mitigation, bending the biodiversity loss curve, relieving pressure in land regarding food and feed production, producing primary resources (including food) with low GHG emissions. There are strong indications that algae, especially macro-algae cultivation, has immense potential to provide a wide range of solutions in a multitude of issues. Macro-algae have the potential to successfully to remove excess nutrients from the water column and improve the coastal water quality in degraded areas. There seems to be great potential in becoming a sustainable, low emission protein and lipid source both for food and for feed, providing also an answer to the issues of productive land availability. Macro-algae can also be used as a potential source of biofuel, again presenting the benefit of reducing pressure in land. Additionally, there is evidence showing that macro-algae aquaculture establishment can act as soft measures of coastal protection, reducing wave and current energy, while there is indication that these kind of farms can have positive effect in maintaining and increasing local biodiversity. Nevertheless, there are still many questions regarding the feasibility and possible impacts of harvesting this potential and exploiting the aforementioned (and possibly more) ecosystems services.

Background

There is strong need to mitigate climate change, enhance sustainable ecosystem service provisioning and secure biodiversity in coastal and marine areas. This is particularly relevant due to the multisectoral human activities taking place and the need for protection, conservation, and management of coastal and marine ecosystems and natural resources[1]. In this context, the development of macro-algae cultures in these areas offers potential for a range of direct and indirect benefits, by producing sustainable natural resources for food, feed, fuel, cosmetics and bio-active compounds for pharmaceuticals (Campbell et al., 2019[2]); and by maintaining and enhancing local coastal biodiversity (Wood et al., 2017[3]). Macro-algae culture establishment may act as soft measures of coastal protection and that such farms may have positive effects in maintaining and increasing local biodiversity (see Tsiamis et al., 2020[4]).

Regarding climate change mitigation via climate related ecosystem services, it is acknowledged the potential role of macro-algae cultivation counteracting ocean de-oxygenation and acidification and buffer eutrophic waters (e.g., Duarte et al., 2017[5], Halley et al., 2019[6]). However, when it comes to carbon long-term storage (the blue carbon) and carbon mass balance calculations there is a lesser agreement between scientific studies. Relevant examples are Duarte et al., (2017[5]) discussion providing "… *a suite of arguments supporting the consideration of seaweed aquaculture as a tool for climate change mitigation and adaptation, while also identifying possible caveats and limitations"*, namely at global scale; Halley et al., (2019[6]) highlighting that "*Production scale and cost are too limiting to sequester global agricultural CO_2eq"*

[1] Neumann, B., Ott, K. & Kenchington, R. (2017) Strong sustainability in coastal areas: a conceptual interpretation of SDG 14. Sustainability Science 12, 1019–1035 https://doi.org/10.1007/s11625-017-0472-y

[2] 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 - Prioritizing key Knowledge gaps. *Frontiers in Marine Science* https://doi.org/10.3389/fmars.2019.00107

[3] Wood D., Capuzzoa E., Kirbya D., Mooney-McAuley K., Kerrison P. (2017) UK macroalgae aquaculture: What are the key environmental and licensing. *Marine Policy* http://dx.doi.org/10.1016/j.marpol.2017.05.021

[4] Tsiamis, K., Salomidi, M., Gerakaris, V. *et al.* (2020) Macroalgal vegetation on a north European artificial reef (Loch Linnhe, Scotland): biodiversity, community types and role of abiotic factors. *Journal of Applied Phycol*ogy https://doi.org/10.1007/s10811-019-01918-2

[5] Duarte C.M., Jiaping W., Xi X., Annette B., Dorte K.-J. (2017) Can Seaweed Farming Play a Role in Climate Change Mitigation and Adaptation? *Frontiers in Marine Science* https://doi.org/10.3389/fmars.2017.00100

[6] Halley E. Froehlich, Jamie C. Afflerbach, Melanie Frazier, Benjamin S. Halpern (2019) Blue Growth Potential to Mitigate Climate Change through Seaweed Offsetting. *Current Biology* https://doi.org/10.1016/j.cub.2019.07.041

at large scale; and Trevathan-Tackett et al., (2015[7]) study showing that marine macroalgae *"(…) may be more valuable to long-term carbon sequestration than we previously have considered*". Therefore, more knowledge is required to evaluate the role of cultivated macro-algae in all dimensions of potential benefits. In addition, the impact of global change, namely oceanographic conditions affecting wild populations (e.g. Yan et al., 2016[8], Wang et al., 2019[9]) can potentially affect coastal and offshore macro-algae cultivation.

Overall, there are indications that algae, especially macro-algae cultivation, has potential to sustainably provide a wide range of benefits through ecosystem services (*e.g.* Valderrama et al., 2013[10]; Jacquim et al., 2014[11]; Hasselström et al., 2018[12]). The potential is further highlighted by a finding, that positive impacts of macro-algae occur in large geographical scales, while negative impacts are local (Hasselström et al., 2018[7]).

However, cautiousness is needed before upscaling macro-algae culture due to uncertainties including effects on local biodiversity (e.g., displacement of wild stocks, occurrence of non-indigenous species) (FAO, 2018[13]), challenges emerging when scaling up the production (e.g., related to climate change and seaweed aquaculture technologies like strain development, harvesting, transport and processing) (Kim et al., 2017[14]) and potential trade-offs and negative impacts (e.g., Jean-Baptiste et al., 2019[15]). Therefore, there is a need to map existing knowledge and identify knowledge gaps and trade-offs, to inform future development of macro-algae culture strategies and policies. Existing assessments mention for example following knowledge gaps relating to positive and negative effects of macro-algae, scale of effects and potential cumulative impacts of various macro-algae farms, and knowledge gained by systematic monitoring (Wood et al. 2017[3]). Furthermore, more knowledge is needed to evaluate impacts in terms of water, energy and land use, changes in sedimentation rates and structure of local communities, and potential pollution and risk of releasing invasive species into the environment (https://ec.europa.eu/jrc/en/science-update/algae-biomass-production-bioeconomy).

Given the above-mentioned uncertainties regarding the potential of macro-algae culture to provide range of benefits and ecosystem services, the aim of this request is to map and screen existing scientific knowledge on potential of macro-algae culture to provide ecosystem services with particular emphasis on related knowledge gaps. Technical know-how could be considered if experts find it relevant in the context of biodiversity and/or ecosystem services, and up-scaling macro-algae production in a way that overcomes possible trade-offs. The scope of the Eklipse work will be framed more specifically by experts group nominated via open call for experts to conduct the assessment. Initial framings highlight focus on 1) off-shore and coastal macro-algae cultivation (with options open to include land-based cultivation if the experts consider those as essential; through-flow land-based cultivation systems can be considered when using coastal waters). 2) Potential of macro-algae cultivation to provide ecosystem services and related

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[7] Trevathan-Tackett, Stacey, Kelleway, Jeffrey, Macreadie, Peter I., Beardall, John, Ralph, Peter and Bellgrove, Alecia (2015) Comparison of marine macrophytes for their contributions to blue carbon sequestration, Ecology, vol. 96, no. 11, pp. 3043-3057. https://doi.org/10.1890/15-0149.1

[8] Yan J., Zhiguang X., Dinghui Z., Kunshan G. (2016) Ecophysiological responses of marine macroalgae to climate change factors. *Journal of Applied Phycology*. 28. https://doi.org/10.1007/s10811-016-0840-5.

[9] Wang M, Hu C, Barnes BB, Mitchum G, Lapointe B, Montoya JP. (2019) The great Atlantic Sargassum belt. Science 365 (6448) 83-87. https://doi.org/10.1126/science.aaw7912

[10] Valderrama, D., Cai, J., Hishamunda, N. & Ridler, N., eds. (2013) Social and economic dimensions of carrageenan seaweed farming. *Fisheries and Aquaculture Technical Paper* No. 580. FAO. 204pp. http://www.fao.org/3/a-i3344e.pdf

[11] Jacquin, A., Brule-Josso, S., Cornish, M.L., Critchley, A.T., Gardet, P. (2014) Selected comments on the role of algae in sustainability. *Journal of Advances in Botanical Research* https://doi.org/10.1016/B978-0-12-408062-1.00001-9

[12] Hasselström L., Visch W., Gröndahl F., Nylund G.M., Pavi H. (2018) The impact of seaweed cultivation on ecosystem services - a case study from the west coast of Sweden, *Marine Pollution Bulletin* https://doi.org/10.1016/j.marpolbul.2018.05.005.

[13] FAO (2018) The global status of seaweed production, trade and utilization. Globefish Research Programme Volume 124. Rome, 120p. Licence: CC BY-NC-SA 3.0 IGO.

[14] Kim J.K., Yarish C., Hwang E.K., Park M., Kim Y. (2017) Seaweed aquaculture: cultivation technologies, challenges and its ecosystem services *Algae* https://doi.org/10.4490/algae.2017.32.3.3

[15] Jean-Baptiste E.T., Ramos F.S., Gröndahl F. (2019) Identifying Suitable Sites for Macroalgae Cultivation on the Swedish West Coast. *Coastal Management* https://doi.org/10.1080/08920753.2019.1540906

trade-offs and uncertainties especially if up-scaling the cultivation (excluding policy analysis, scenario analysis or assessments of strictly technical know-how, but including potential synergies with other Blue Growth activities), and 3) strong focus on identification of knowledge gaps on ecosystem services and macro-algae cultivation. The Eklipse exercise will take into account qualitative and quantitative data. Such assessment is needed to critically assess potential on macro-algae culture to serve as a solution to mitigate climate change, enhance coastal biodiversity and sustainable ecosystem service provisioning. Eklipse results can inform any future algae research or Commission activities. Identification of knowledge gaps can therefore inform future research and action on macro-algae, as a sustainable natural resource.

Already identified projects and networks

Here we briefly flag out some previous and existing projects and networks.

The Horizon 2020 Blue Growth project GENIALG[16]. This is the first industry-driven project bringing together pioneering companies in large-scale integrated European biorefineries and experts in seaweed cultivation, genetics and metabolomics to boost the seaweed industry.

GENIALG & IDEALG Final Conference 2020, November 30th: "Seaweed for the Future: Scaling-up the European Sector"[17]

EU COST Action PHYCOMORPH publications:
PEGASUS - Phycomorph European Guidelines for a SUstainable Aquaculture of Seaweeds[18]
MACROFUELS: Macro-algae as a sustainable source for biofuels (https://www.wur.nl/en/project/MACROFUELS-Macro-algae-as-a-sustainable-source-for-biofuels.htm)

Algae-related conferences and knowledge transfer

- SEAGRICULTURE 2020; 24 - 25 Sep 2020 online[19]. 9th International Seaweed Conference: "Seaweeds: supporting the European Green Deal"
- The 2020 Algae Biomass Summit, by AB the Algae Biomass Organization: "Algae 2020 - Sustainable, Scalable Solutions"[20]
- AlgaEurope conference 2020; 01-04 Dec 2020 online[21]. This conference gathers algae-related researchers (academia) and industry; in their words it is a conference where European algae scene meets
- EABA ALGAE WORKSHOPS 2020, by EABA the European Algae Biomass Association[22]: "Promoting mutual interchange and cooperation in the field of biomass production and use, including biofuels uses and all other utilisations"
- ALGAL BIOTECHNOLOGY 2020 – TECHNIQUES AND OPPORTUNITIES FOR THE SUSTAINABLE BIOECONOMY[23]: "The aim of this online professional development course is to provide introductory training and theory in algal biology, culturing, growth and biotechnology under laboratory and small scale pilot facilities"

Policy relevance and timeliness of the request

It has been noted that the algae sector contributes to the EU blue bioeconomy and holds great potential for development in terms of employment and the economy, especially for coastal and remote areas.

[16] https://genialgproject.eu
[17] https://genialgproject.eu/about-the-conference/
[18] *http://www.phycomorph.org/doc/PEGASUS_SUSTAINABLE_SEAWEED_AQUACULTURE_FULL_RECOMMENDATIONS.pdf*
[19] https://seagriculture.eu
[20] https://www.algaebiomasssummit.org
[21] https://algaeurope.org
[22] https://algaeworkshops.org/
[23] https://www.eitfood.eu/projects/algal-biotechnology-techniques-and-opportunities-for-the-sustainable-bioeconomy-2020

Furthermore, According to the EU Blue Economy report of 2019, the EU algae sector has an annual turnover of €1.5 billion for direct activities (with indirect activities such as research adding an additional €240 million) (Cited from: https://ec.europa.eu/jrc/en/science-update/algae-biomass-production-bioeconomy).

The main policy context of this request is the EU Green Deal Strategy[24] and the EU Blue Bioeconomy sector that is part of the EU Blue Growth Strategy[25].
The issues related to macro-algae culture touch upon different aspects of the new EU Green Deal Strategy:
a) Increasing EU's climate ambition for 2050 (low emission food and feed production; increase CO_2 sequestration);
b) the Farm to Fork strategy (through sustainable protein production and contribution to food security);
c) the Zero pollution ambition (through the removal of excess of nutrients, i.e., mitigate coastal waters eutrophication by culturing fast-growing species that can be harvest and used as clean natural resource (e.g., Xiao et al., 2019[26]); and through the removal of other chemicals including dangerous substances, i.e., use of macro-algae biomass as an adsorbent in wastewater treatment (Arumugam et al., 2018[27]);
d) Preserving and restoring ecosystems and biodiversity (by contradicting ocean acidification and ocean de-oxygenation, and by enhancing habitat complexity); and
e) Supplying clean and possible affordable energy (through the production of biofuels).
Macro-algae culture is also one of the aquaculture activities included in the Blue Bioeconomy sector. This sector includes the economic activities associated with the use of renewable aquatic biological resources to make products (e.g., *novel foods and food additives, animal feeds, nutraceuticals, pharmaceuticals, cosmetics, materials and energy*)[28].

In addition, Macro-algae cultivation can link to and advance various UN Sustainable Development Goals (see https://blogs.helsinki.fi/potentalgae/).

Taking into consideration the various areas where macro-algae culture can contribute in the Green Deal, but also the importance of the overall algae sector for the development of a sustainable European Blue Bioeconomy, the identification of possible knowledge gaps or knowledge needs related to the subject can inform any future algae research or Commission activities.

Added Value of Eklipse

- It would provide an independent expert opinion and robust knowledge on an issue where diverse opinions exist including the main one that algae are the panacea solving the main problems related to bioenergy, functional food, feed, and bio-active compounds for cosmetics and pharmaceuticals. When implementing solutions, it is important to avoid adverse effects on biodiversity and ES and ensure long-term sustainability.
- A synthesis presenting what we know and what we don't know would be very beneficial, informing the debate/discussions on macro-algae cultivation and the provided ES, including blue carbon, as well as on macro-algae cultivation and marine biodiversity.
- Added value in comparison to independent studies is that Eklipse can use many methodological steps in the process to answer the specific knowledge need by the requester, and facilitate inputs from heterogeneous expert community in structured manner.

[24] https://ec.europa.eu/info/sites/info/files/european-green-deal-communication_en.pdf
[25] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=COM:2014:254:REV1&from=EN
[26] Xiao, X., Agusti, S., Lin, F. et al. Nutrient removal from Chinese coastal waters by large-scale seaweed aquaculture. Sci Rep 7, 46613 (2017). https://doi.org/10.1038/srep46613
[27] Arumugam N., Chelliapan S. , Kamyab H. , Thirugnana S. , Othman N., Noor Shawal Nasri N.S. (2018) Treatment of Wastewater Using Seaweed: A Review. Int. J. Environ. Res. Public Health 2018, 15, 2851; https://doi.org/10.3390/ijerph15122851
[28] https://www.eumofa.eu/documents/20178/84590/Blue+bioeconomy_Final.pdf

- Added value in comparison to policy work on the macro-algae culture is ability to mobilise targeted knowledge co-production process, where the requester can play a crucial role yet with flexibility to identify other issues, uncertainties and emerging themes, especially relevant for identifying further research needs, which can be addressed by next generation of EC R&I funding calls.
- Ability to engage range of experts to identify knowledge gaps in the field. It can be expected that Eklipse work on knowledge gaps can be more extensive if compared to scoping by individual researchers or even research groups.

Call for Knowledge

A Call for Knowledge related to this request was launched end of September and was open until November 6th 2020 (extended from 23rd October 2020). The Call for Knowledge was broadly disseminated through the different Eklipse social media platforms, i.e. LinkedIn, ResearchGate, Twitter, Facebook, Instagram as well as via different mailing lists and networks (e.g. Euromarine, Algae Europe, The European Macro-algae community, etc…). This Call for Knowledge was the first Eklipse Call for Knowledge using the Eklipse Forum on LinkedIn as main platform with the initial aim to centralize the discussion and contribution.
Contributions to the LinkedIn forum highlighted the following publications:

- Krause-Jensen et al (2018) https://doi.org/10.1098/rsbl.2018.0236
- Froehlich et al (2019) https://doi.org/10.1016/j.cub.2019.07.041
- Book Spirulina by Marianne E Meyer (2016)
- Book Doktor Chlorella by Frank Liebke (2007)

The Eklipse Forum was thought as the successor of the Eklipse KNOCK forum. With insights from this Call for Knowledge, the next Eklipse Calls for Knowledge will not try to redirect the discussion towards LinkedIn Eklipse Forum but will let the discussion happening in all the different social media platforms (ResearchGate, Twitter, Facebook, Instagram, etc..) as well as let anyone willing to participate using their preferred mean to contribute, e.g. emailing directly to the EMB would also be an option proposed

REFINED RESEARCH QUESTION

What are the knowledge gaps to be addressed before harvesting the potential of macro-algae culture in providing climate-related and other ecosystem services (i.e. coastal protection; nutrient recycling; lower impact food; lower impact material; etc.) especially in larger scale?

SUGGESTED PROGRAMME OF WORK AND METHODS

The key issue for the request is to take stock of existing knowledge on macro-algae cultivation and the provided ecosystem services and identify existing knowledge gaps, following a critical and robust assessment. In the words of the requester - *A report summarising the sources of synthesised knowledge, assessing the quality and quantity of information regarding the macroalgae cultivation (including possible spatial and temporal considerations, should they arise) and identifying the major gaps regarding the issue*. Due to an emerging but rather dispersed body of literature (e.g., scientific papers and reports and grey literature) on macro-algae cultivation related issues, there is a need to narrow the topics to be addressed. **Initial framings** discussed with the requester (DG MARE) excluded focus on policy pathways and policy issues (Internal EC work has already been done on all legislative documents related to macro-algae cultivation and more work is to follow). Technical know-how and best practice of macro-algae culture is

not the main focus but could be considered if biodiversity and/or ecosystem services relevant (e.g. macro-algae infrastructure of production and potential of scaling up). Among the ES to be considered, DG MARE mentioned:

a) regulating and maintenance services (less is known about these) including climate-change related ES, coastal areas protection, ability of seaweeds to filter nutrients (these come up a lot in discussions) and provisioning of habitat and associated biodiversity;
b) cultural services (but maybe too far: e.g. value change in food production and consumption; coastal recreation);
c) provisioning services (e.g. biomass production)… but would like to capture other issues too, namely conflicting issues and trade-offs.

Although the topic has already been refined, further framing is needed for Eklipse's work.

Eklipse Method Expert Group suggests the following possibilities for methods:

Summary of the methods proposed to answer the request: Rapid evidence assessment (REA); Scoping review; Multiple expert consultation with Delphi process. Multiple expert consultation collates opinions, which is not the case for literature reviews. Miriam Grace, the MEG focal point for this request would advise the use of a quick-scoping review or REA. The difference is that REA includes a critical appraisal of evidence. Each reviewed document is given a relevant score. It would be more work but provides more robust results.
Therefore, Delphi could be used to identify key issues and prioritize them, and a scoping review could be used to assess what is known and what is not known on the prioritized items identified in Delphi. A further multiple expert consultation could complement this as a third step.

A possibility could be a three step approach consisting of 1) Delphi process to identify and prioritize key topics, 2) a scoping review (or similar) to assess knowledge gaps in the priority areas identified in Delphi, and 3) expert consultation workshop to discuss and verify results of the previous steps. Initial thoughts about these three steps and used methods are provided below.

1) **Delphi process** in the first round would identify key areas where knowledge is needed by for example following questions:

- What are the ES macro-algae cultivation can provide?
- What negative impacts / trade-offs may macro-algae cultivation include?
- What uncertainties need to be resolved before significantly increasing / scaling up macro algae culture?
- What are future research needs on macro-algae cultivation and the provided ES?
- What are possible unexpected / emerging issues included in scaling-up macro-algae culture?

In general, these questions should allow Delphi panelists to identify key issues and knowledge gaps as well as present doubts about macro-algae culture being a panacea. The first round of the Delphi would identify rather long lists of issues. The Eklipse EWG will then cluster the items on the lists. In the second round of the Delphi, Eklipse would ask panelists to prioritize identified items under each question. This will result in a set of issues and priorities to inform the scoping review (or other chosen method to identify knowledge gaps). In addition, the question on future research needs will directly inform DG Mare on how expert communities perceive needs for future research thereby contributing to drafting forthcoming Horizon Europe calls. Also, the wide range of ES potentially produced by macro-algae culture will be identified and prioritized in the Delphi process.

2) **The scoping review (or other method to identify knowledge gaps),** will then be narrowed down by prioritized lists of issues. Yet, some flexibility is allowed for the EWG to conduct the assessment of the knowledge gaps, and also choice of the exact method to be used to identify knowledge gaps.

3) **A third step** could be used if there are enough time and resources. This would consist of another multiple expert consultation, where selected group of experts could discuss the findings of the Delphi and scoping review. This could take a form of a workshop. There may be funds available from the requester to arrange this. This step could ensure the comprehensiveness of the findings, confirm key knowledge gaps, and deliberate on future research needs. A face to face workshop would allow more in-depth discussions than the rather technical Delphi process. Workshop participants could be identified by using past projects (e.g. PEGASUS; OTHERS) and Annual Seaweed Conference as starting points. Given the Covid-19 situation, a face-to-face workshop may be difficult to arrange, bur virtual meeting options can be considered, if the EWG and requester consider this would add value.