METHOD PROTOCOL

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

Requested by DG-Mare

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Eklipse Expert Working Group

Draft method protocol
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Eklipse Expert Working Group Macroalgae

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0.1	Expert Working Group (EWG)	15/05/2021	For review by the MEG
0.2	Methods Experts Group (MEG): Miriam Grace and Laura Wendling	04/06/2021	Comments and suggestions to the EWG
1.0	EWG	15/06/2021	For public review

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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 distinct from the goods and benefits that people subsequently derive from them	www.cices.eu; Haines-Young, R. & M.B. Potschin, 2018
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 <50m water depth & <3 nautical miles distance to shore	Bak et al. (2020)
Near-shore, exposed	cultivation of macroalgae in marine waters >50 meters depth & <3 nautical miles from shore	Bak et al. (2020)
Offshore	>3 nautical miles from shore	Bak et al. (2020)

INTRODUCTION

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 to anthropogenically-induced problems. There is strong evidence that macroalgae aquaculture establishment and growth can potentially mitigate climate change, protect coastlines, reduce local biodiversity loss, and provide a number of other ecosystem services. 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 macroalgal cultivation in Europe can grow 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 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, and potential pollution and risk of releasing invasive 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 Bio-economy. The successful development of this strategy requires that the knowledge gaps, constraints, and potential negative impacts related to macroalgae cultivation are identified in order to advise, through DG MARE, the development of relevant research activities under the next EMFF and Horizon Europe programmes. Therefore, the requester posed these 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 primary questions, the Expert Working Group (EWG) on Macroalgae was established. 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. 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 organized 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.

OBJECTIVES

The following two objectives are identified:

1. To collect, review, and summarize the current state of knowledge regarding 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.)
2. To identify specific knowledge gaps to be addressed before harvesting this potential

FOCUS OF THE REQUEST

By using qualitative and quantitative data this work will focus on the following points:

- The focus is on off-shore and coastal macroalgae cultivation (with options open to include land-based cultivation) at all stages of the production chain, from the nursery stage through to the processing and marketing phases.
- Potential of macroalgae cultivation to provide ecosystem services and related trade-offs and uncertainties, especially if up-scaling the cultivation, but including potential synergies with other Blue Growth activities.
- Strong focus on identification of knowledge gaps on ecosystem services and macroalgae cultivation.

METHODOLOGY

This section describes the methodology proposed for the Working Group in a two-step approach. In the first step – the methodological framework – we describe the methods in general, in relation to the objectives and to each other. The second section will describe the methods proposed in more detail.

METHODOLOGICAL FRAMEWORK

To achieve the objectives formulated above, a combination of the following two methods is proposed: Quick Scoping Review (QSR) and a Multiple Expert Consultation with Delphi Process. These methods will be conducted in parallel, rather than sequentially. A first round of questions will be sent to selected experts as part of the Delphi Process, and then we will proceed with the QSR. The use of the two methods helps to provide a more comprehensive answer to the request than the use of a single method. QSR focuses on peer-reviewed literature, and the Delphi method captures the

most recent and up-to-date views of experts from key sectors, including science, business and NGOs. Therefore, while QSR provides a robust view on published literature and evidence, Delphi covers views of not only scientists, but also other societal actors with practical and experience-based knowledge on the key issues in macroalgae cultivation.

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

Questions	Quick scoping review	Delphi method
What is the state-of-knowledge?	• Provides synthesis of relevant literature • Generates knowledge base to hold against results from Delphi	• Identify and prioritize ecosystem services considered relevant • Identify constraints for up-scaling • Identify 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 • Formulate pathways to fill these gaps

QUICK SCOPING REVIEW (QSR)

The method of QSR aims to provide an informed conclusion of the quantity and quality of research evidence relevant to a question or issue, together with a summary of what that evidence indicates.

The QSR will be conducted in three phases. The first phase will be a structured search of the scientific and grey literature to summarize the current state of the knowledge and to identify potential contrasting evidence, which might indicate knowledge gaps or the need for further investigation. The second phase will involve a consolidation of the most relevant scientific articles selected in phase 1 and supplemented by suggestions from the experts questioned during the Delphi process. The final stage will consist of a synthesis of the selected literature.

As a preliminary exploration of the literature, Google Scholar was used to search for relevant scientific publications on April 20. All the searches included all of the following keywords (as some of these are synonyms):

- Macroalgae

- Seaweed
- Cultivation
- Farming
- Aquaculture

And then only one of the following keywords, one at a time:

- climate change
- invasive species
- impacts
- arsenic
- bromine
- ecosystem services
- greenhouse
- value chain
- biosecurity
- carbon
- bioremediation

Only papers published since 2000 were considered. Review papers were included, but books were excluded. This resulted in 442 research papers that were saved in a dedicated Mendeley library. The first phase will use all possible combinations of the primary terms “macro alga*”, “macro-alga*” “macroalga*” and “seaweed”, and the secondary terms “cult*”, “farm*” and “aquaculture”. Due to the general nature of ecosystem services, more specific terms were avoided to minimise bias during the search. In order to reduce the number of unrelated literature, quotation marks were used for combination and search. All searching results, along with the date of search and the term used, will be recorded to ensure reliability and transparency. Searches will be developed in the databases “Scopus” and “Web of Knowledge” (Collings et al., 2015).

In the second phase, an initial screening will be done to exclude review papers, where these are not automatically selected out. Inclusion of review papers leads to the risk of double-counting; hence the Expert Group proposes to focus on original first-hand results only that present a properly described methodology.

Next, papers will be divided among experts who will assess evidence related to ecosystem services provided by seaweed cultivation. Each article will be assessed by at least two different experts. Articles will be classified according to article type, species, geographic region, the scale and type of cultivation, the sector to which the study belongs, the ecosystem services provided, and identified constraints, including knowledge gaps and negative impacts or trade-offs (e.g., see classification scheme below).

Expected outputs of the scoping review include a bibliography of publications on macroalgae cultivation and ecosystem services, a summary of the number of studies conducted using each aquaculture method, a quantitative analysis of the known ecosystem services that macroalgae cultivation can provide, including indications of the level of uncertainty, and a list of services and disservices. Additionally, we will provide a summary table of the main knowledge gaps that were identified in the literature (see more details below in the organization of data and visualisation of findings sections)

DELPHI PROCESS

The Delphi process is an iterative technique for collecting information using expert consultation in a structured manner in order to produce forecasts and evaluate complex problems. This method was originally described by Dalkey and Helmer (1963) and has since then been adapted to the fields of ecology and 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, and reduces risk of bias. 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, if this is not managed carefully.

The Delphi process will be adapted to address the questions raised by the Expert Working Group on Macroalgae Cultivation. We identified at least 130 experts from 40 countries, 15 of which were EU countries, to participate in 3 rounds of questioning. The geographic distribution of experts will be 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 will also be 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 organizations, 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 method will adopt open questions, very much aligned with the questions provided by the Document of Work for the Macroalgae culture request (February 2021).

For the second round of the Delphi, we will ask the responders to rank the answers provided during the 1st round. Finally, we will have a third round to give the responders the opportunity to review their answers, when compared to the overall ranking arising from the previous round.

Expected output of using the Delphi method in this EWG are

- Insights into relevant ecosystem services of macroalgae cultivation.
- Weighting of the identified ecosystem services.
- Identification of relevant knowledge gaps.
- Weighting of knowledge gaps.
- Proposed pathways for bridging gaps.

EXPECTED APPROACH TO ORGANIZE KNOWLEDGE AND DATA

QUICK SCOPING REVIEW

The data collected in the QSR will be organized for further analysis in an Excel spreadsheet with macros. The following classification scheme will be included:

- Expert name (reviewer)
- Authors
- Year
- Reference
- Type of document
- Species
- Country
- Scale
- Sector
- Aquaculture Type
- Study protocol
    - Before-After Design
    - Control-Impact Design
    - Descriptive
    - Other
    - Modelling
- Farm size
    - Pilot
    - Small
    - Medium
    - Large
- Ecosystem Services
    - Provisioning
    - Regulating and Maintenance

- Cultural
- Constraints
  - Knowledge Gaps
    - Processing
    - Marketing
    - Production
    - Materials
    - Safety
    - Environmental Impacts/Trade-Offs
    - Other
    - None
  - Identified Constraints
    - Technological
    - Political
    - Economic
    - Legal
    - Social
    - Environmental
    - Other
    - None

Additionally, we will prepare a summary table of services and disservices and the main knowledge gaps at the different stages of and in the different sectors surrounding macroalgae cultivation. The classification scheme presented above for QSR identifies key priority areas for the literature review. We use two initial assumptions to help in categorizing the reviewed papers and their insights. First, we use the CICES classification of ecosystem services, to help to identify key knowledge gaps regarding different types of ecosystem services (e.g., provisioning, cultural, regulating and maintenance). Second, we assume that knowledge gaps and constraints for up-scaling macroalgae cultivation may relate to different phases of the value chain and safety issues. These represent areas where knowledge gaps and constraints may be found that are internal to the macroalgae cultivation industry. To identify contextual constraints and knowledge gaps, we make a third assumption that the contextual constraints can be identified by using PESTEL (Political, Economic, Social, Technological, Environmental, Legal) factors. Making this initial assumption, we are able to direct focus on diverse contextual aspects that may be proven relevant during the QSR. We note that despite these initial assumptions and pre-existing classification scheme for the papers, we are also open to generate new categories if justified by the reviewed literature.

DELPHI

While executing the Delphi methodology, the following information will be recorded in Excel:

- Number of participants for each round of the Delphi method.
- Background information of the respondents (e.g., field of expertise, region).
- Number of replies for each round of the Delphi method.
- Collated findings from the Delphi method, per ecosystem services deemed relevant.

In a text document, the following sections will be described:

- Description of the methodology.
- Results, including overview of ecosystem services deemed relevant, knowledge base per ecosystem service and knowledge gaps.
- Discussion, including reflection of strength and weaknesses of method, validity and limitations of the findings.
- Conclusions and recommendations.

VISUALISATION OF FINDINGS

Below we present some possible figures that can be prepared to visualise the results of the QSR and the Delphi method:

1. Pie Chart of the number of studies analysed for each cultivation method (Fig. 1).
2. Bar Chart showing the results of meta-analysis of the ecosystem services provided by macroalgae cultivation, according to species and cultivation type (Fig. 2).
3. A figure of the ecosystem services provided by macroalgae and how they relate to UN sustainability goals (Fig. 3).

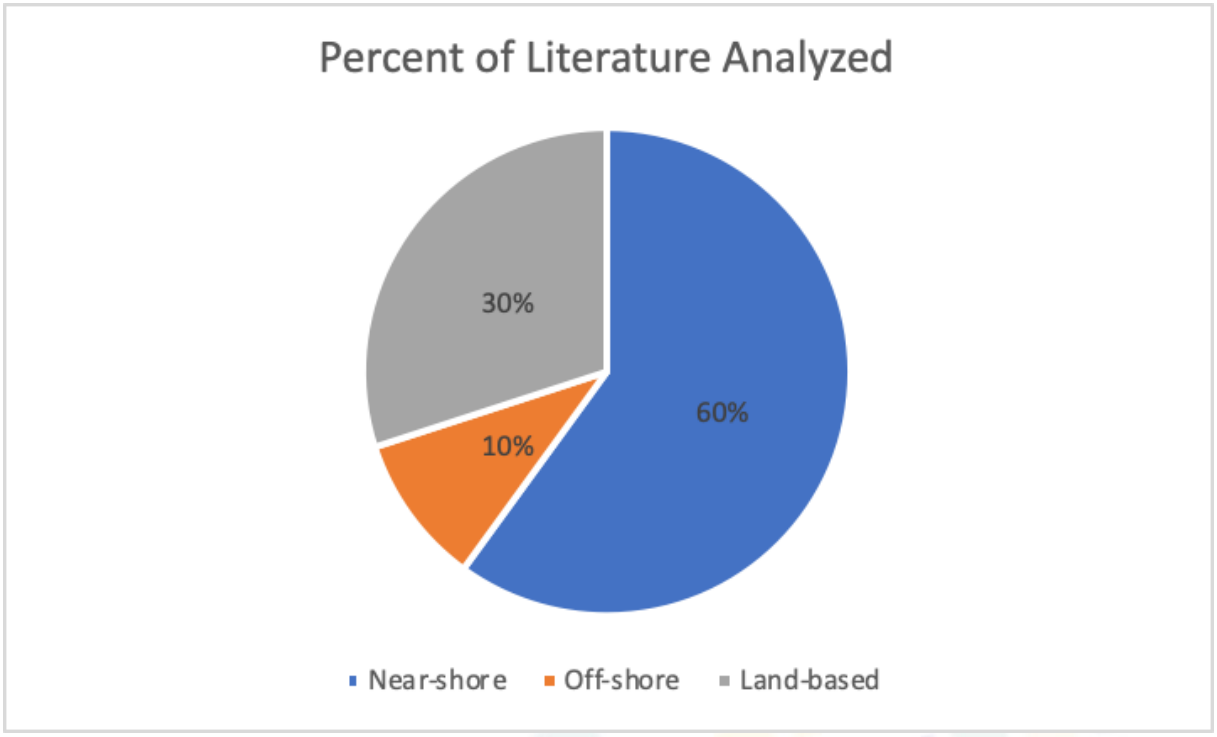

Fig. 1 Example of a pie chart showing the distribution of literature analysed among the types of aquaculture.

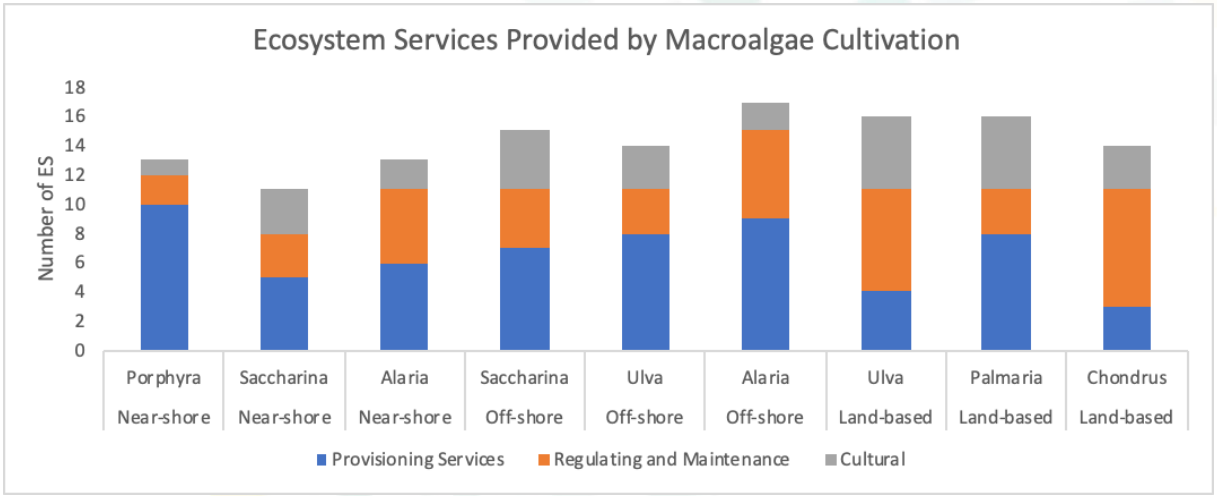

Fig. 2 Example illustrating the analysis of ecosystem services provided by different types and species of macroalgae cultivation.

Fig. 3 Example of a figure showing the ecosystem services provided by seaweed cultivation and how they relate to the UN Sustainable Development Goals.

LIMITATIONS OF THE EXPECTED CONCLUSIONS

Attention within Europe has focused on a limited number (3-4) of macroalgae species, initially driven by biofuels/bioenergy production from macroalgae. There are now other projects focusing on higher value compounds, but again adopting species that have been featured in bioenergy production. It must also be noted that there will be a lag between the research being carried out and the results being published. Results of recent and ongoing research may not be represented in the QSR. Research on the commercial application of new species is developing; however, there is likely to be a lag in the reporting of this in the literature. What should also be noted is that ecosystem services are not always highlighted and there is currently a focus on blue carbon. In addition, only a few aspects linked to climate change and its potential impacts on the developing macroalgal industry and connected ecosystem services have been reported, including the impacts this might have on a developing macroalgal industry and the ecosystem services that this might provide.

EXPECTED RESULTS

The Working Groups expects to deliver the following results:

1) **Identification** of most relevant ecosystem services provided by macroalgae cultivation.

2) Overview of **knowledge gaps** related to these ecosystem services.
3) Insight into **constraints** that hamper the strengthening of ecosystem services provisioning.
4) **Recommendations** to advance macroalgae cultivation and its delivery of ecosystem services.

The following table provides insight into the linkages between expected results and the activities conducted:

Expected results	QSR	Delphi	Expert analysis
Identification	x	x	
Knowledge gaps	x	x	x
Constraints	x	x	x
Recommendations		x	x

309 # TIMELINE

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	Task	March	April	May	June	July	Aug	Sept	Oct
QSR	Phase 1					X			
	Phase 2					X			
	Phase 3					x	X		
Delphi	Preparation	x	x	x	x	X			
	Round 1					X			
	Round 2					X			
	Round 3						X		
Synthesis	Analysis						X		
	Conclusions						X	X	
	Draft final study report						X	X	
	Delivery of final study report								X

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ANNEX I

DELPHI QUESTIONNAIRE PREPARATION DOCUMENT

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.

NOTE FOR SETUP: Always have the options "land-based cultivation, transitional (e.g., estuaries) or marine waters (near shore sheltered, near shore exposed, off shore) or common to some or all of these" visible for all the questions below

DELPHI - 1ST ROUND QUESTIONS

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?

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?

QUESTIONS TO BE MADE BEFORE THE ACTUAL QUESTIONNAIRE, FOR BACKGROUND ASSESSMENT.

NOTE FOR SETUP: Whenever possible give the possibility so select from a list or tick boxes, rather than make the responder type all the answers. Always with a field "other" to type something.

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 cultivation

☐ Macroalgae processing

☐ Macroalgae production

☐ Marketing and sales

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

☐ Asia and the Pacific:

☐ Near East:

☐ Europe:

☐ North America:

☐ Latin America and the Caribbean:

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)

Please choose your work area (click here)

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

☐ 1 – 5 years

☐ more than 20 years

☐ 6-20 years