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

Report prepared for Eklipse by Macroalgae EWG & MWG

EWG

Bermejo, R**,** Buschmann, A, Capuzzo, E, Cottier-Cook, E, Fricke, A, Hernández, I, Hofmann, LC, **Pereira, R**, van der Burg, S.

MWG

Grace, M, Mukherjee, N, Wendling, L

More information: https://eklipse.eu/request-macroalgae/

Requester: DG Maritime Affairs & Fisheries, Unit for Maritime Innovation, Marine Knowledge and Investment.

Background:

This request 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 and land use, changes in sedimentation rates and structure of local communities, and potential pollution and risk of releasing invasive species into the environment and can contribute to the development, promotion and implementation of adequate and timely policy frameworks.

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

Delphi

Pros	Cons
• Updated information • Direct answers • Rapid • Low cost • Rigorous • Repeatable	• Time consuming • Respondent willingness • Bias by strong opinions • Bias by expertise/sector • Prone to conflict of interest

Quick Scoping Review

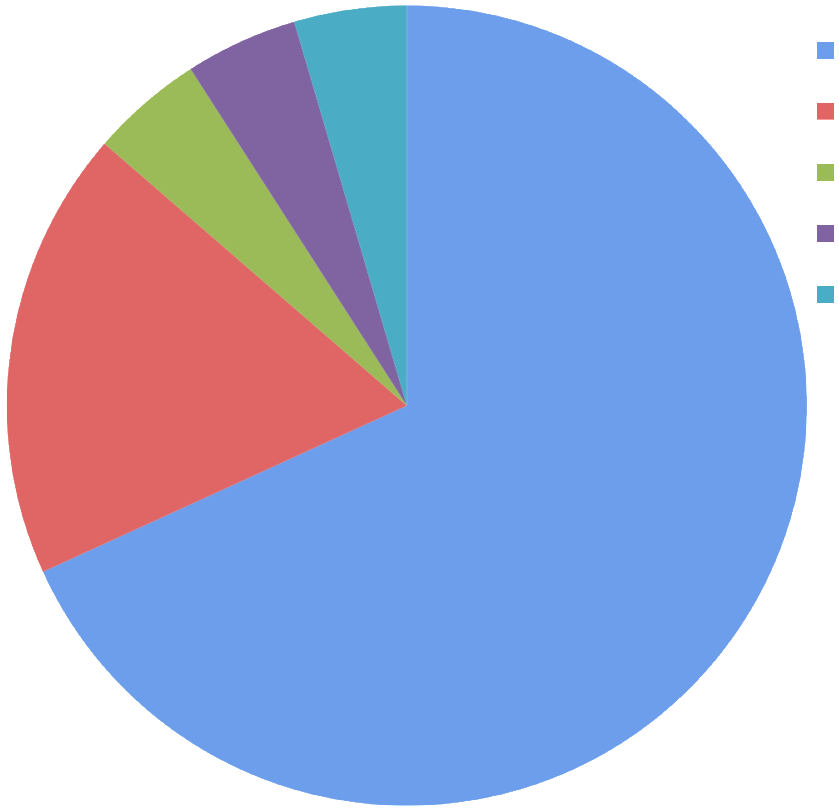
Pros	Cons
• Peer-reviewed findings • More objective • Less conflict of interests • Relatively fast • Low cost • Rigorous • Repeatable	• Time lag • Indirect answers • Bias by funding • Bias by expertise • No assessment

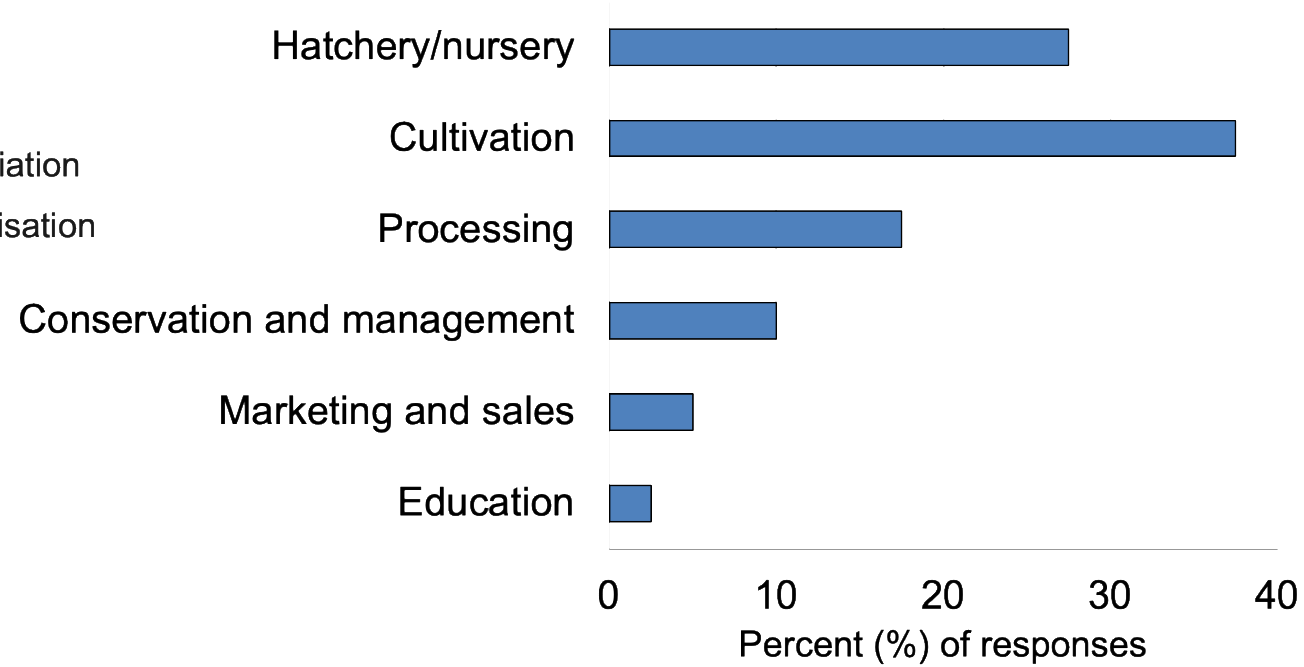
Delphi methodology

We identified more than 100 possible respondents, aiming to get a diverse geographical (but focused on Europe) and sectorial representation

>100 respondent invited → Only **22 respondents, participated** in the 1st round, mainly from academia

22 respondent invited 2nd round → Only **6 responses**





Delphi methodology

Ecosystem services	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 (CO_2, 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

Potential negative impact or trade-off	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

Delphi methodology

Knowledge gaps category	Average Score	Sub-categories
Farming technologies	2.3	Strain improvement
		Ensure consistent production quality
		Develop mechanisation
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
Policy	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

QSR methodology

Keywords:

Seaweed
Macroalga*

+

Aquaculture
Farm*
Cult*

=

6 combinations
(e.g. “Seaweed Cult*”)

Databases:

WEB OF SCIENCE™

Inclusion/exclusion criteria:

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

QSR methodology

Identification

Records retrieved from Web of Science Core Collection searching (n = 845)

Records retrieved from Scopus searching (n = 1,054)

Screening

Records after duplicates removed (n = 1,229)

Records after articles not meeting eligibility Phase 1 criteria removed (n = 960)

Records after articles not meeting eligibility Phase 2 criteria removed. Title and abstract review. (n = 381)

Eligibility

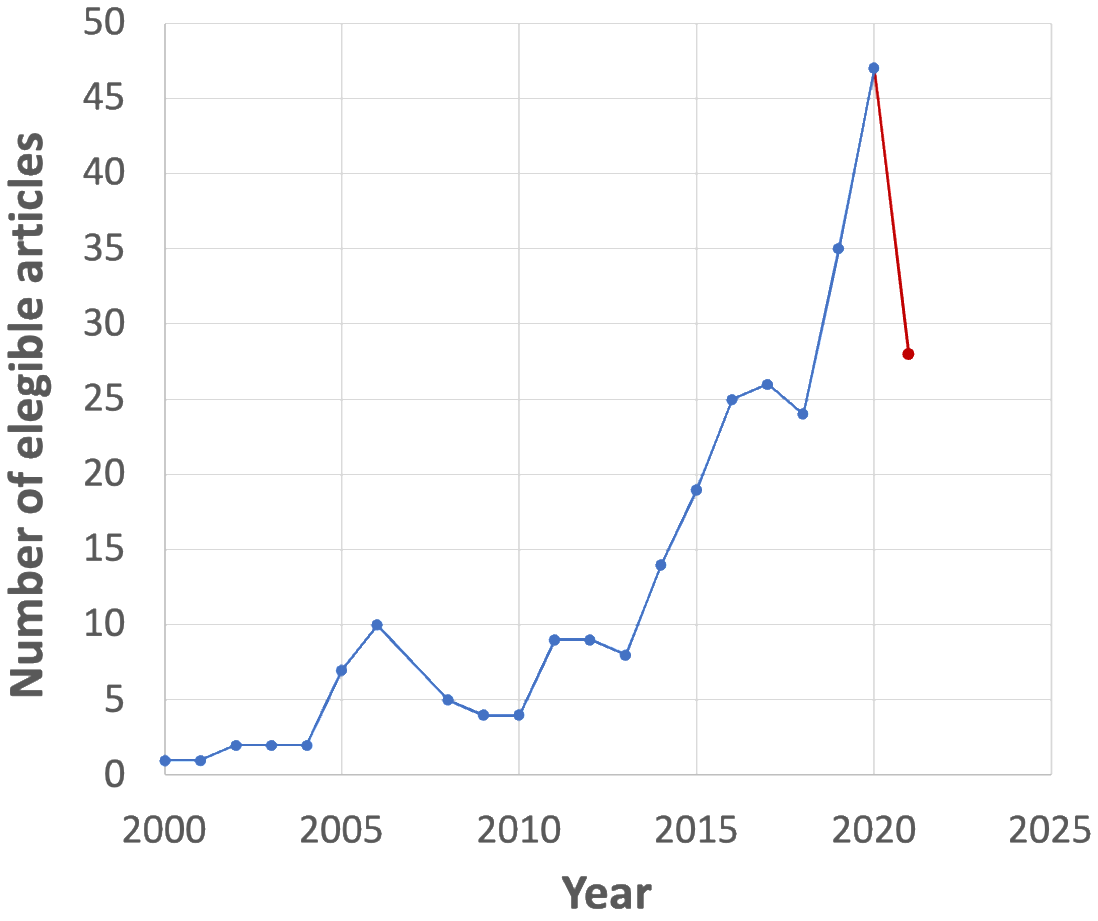
Records after articles not meeting eligibility Phase 3 criteria removed. Full-text article review. (n = 280)

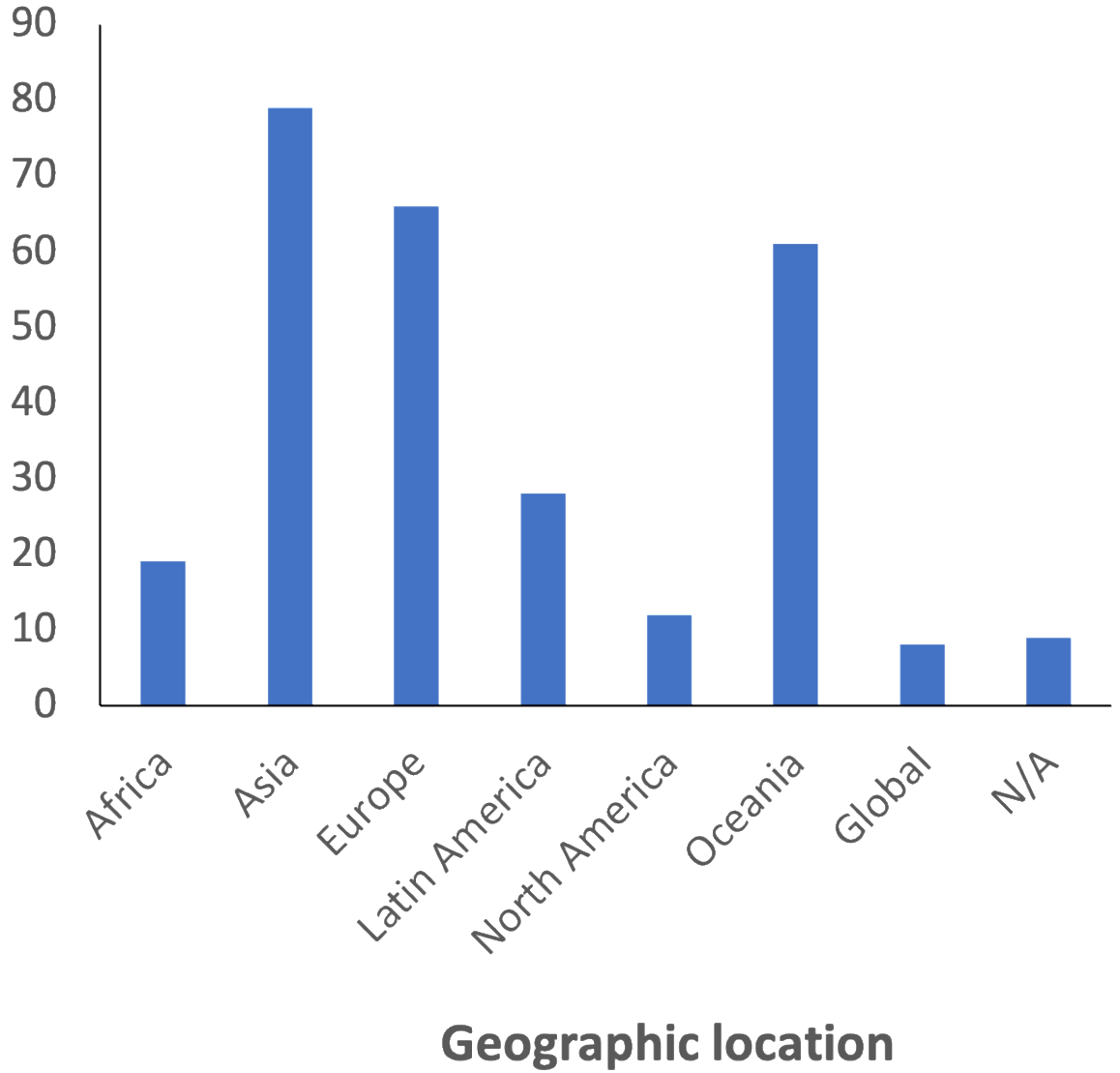
All these studies were considered for further analyses and evidence extraction

Information extracted:

- Year
- Location (Continent)
- Species (taxonomic group)
- Type of farm
- Size of farm
- Ecosystem services
- Identified constraints
- Identified negative impacts/risks

QSR results


Number of elegible articles
50
45
40
35
30
25
20
15
10
5
0
2000
2005
2010
2015
2020
2025
Year


90
80
70
60
50
40
30
20
10
0
Africa
Asia
Europe
Latin America
North America
Oceania
Global
N/A
Geographic location

QSR results

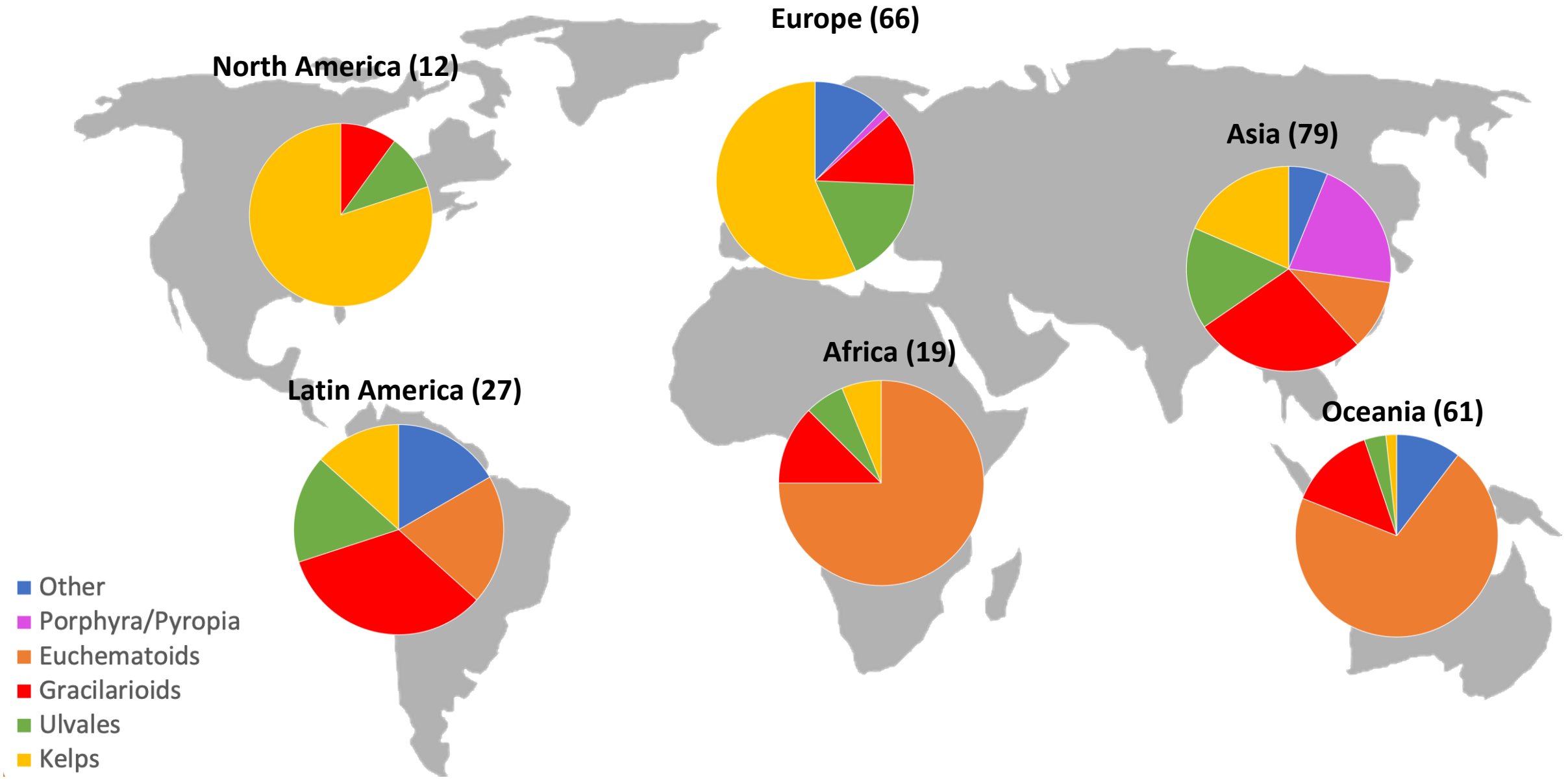
280 Eligible Articles

37 Genus comprising 77 species, but potential taxonomic mismatches (e.g. *Ulva*, *Gracilaria*, *Porphyra*)

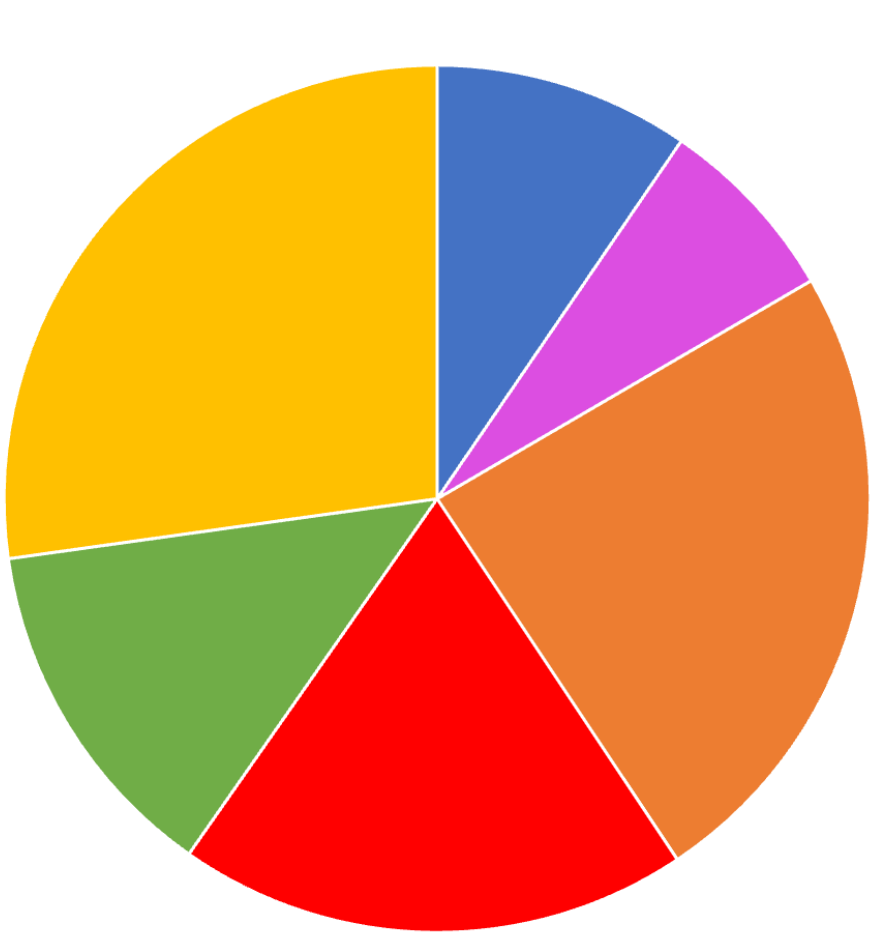
In Europe:
11 genus comprising 17 species
4 non native species

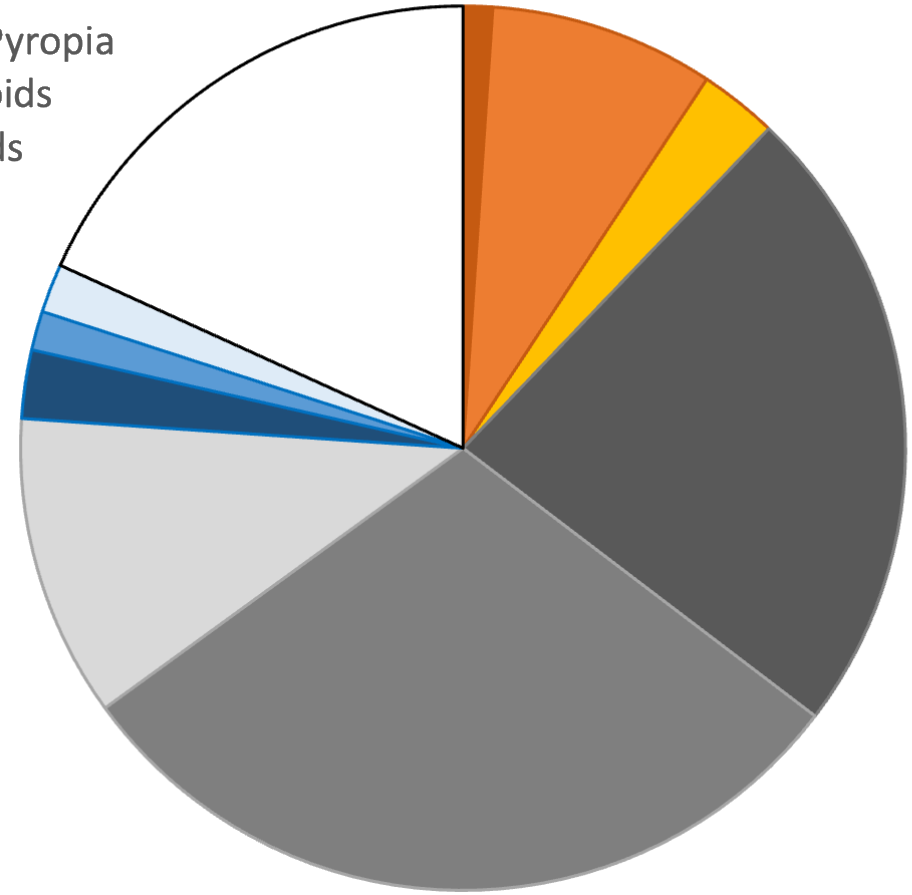
	Species	Studies (%)
1	*Ulva intestinalis*	4
2	*Ulva lactuca*	2
3	*Ulva rigida*	4
4	*Ulva rotundata*	5
5	*Asparagopsis armata**	4
6	*Asparagopsis taxiformis**	2
7	*Chondracanthus teedei*	4
8	*Furcellaria lumbricalis*	2
9	*Gracilaria bursa-pastoris*	2
10	*Gracilaria gracilis*	4
11	*Gracilaria vermiculophylla**	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

QSR results


Europe (66)
North America (12)
Asia (79)
Africa (19)
Latin America (27)
Oceania (61)
Other
Porphyra/Pyropia
Euchematoids
Gracilarioids
Ulvales
Kelps

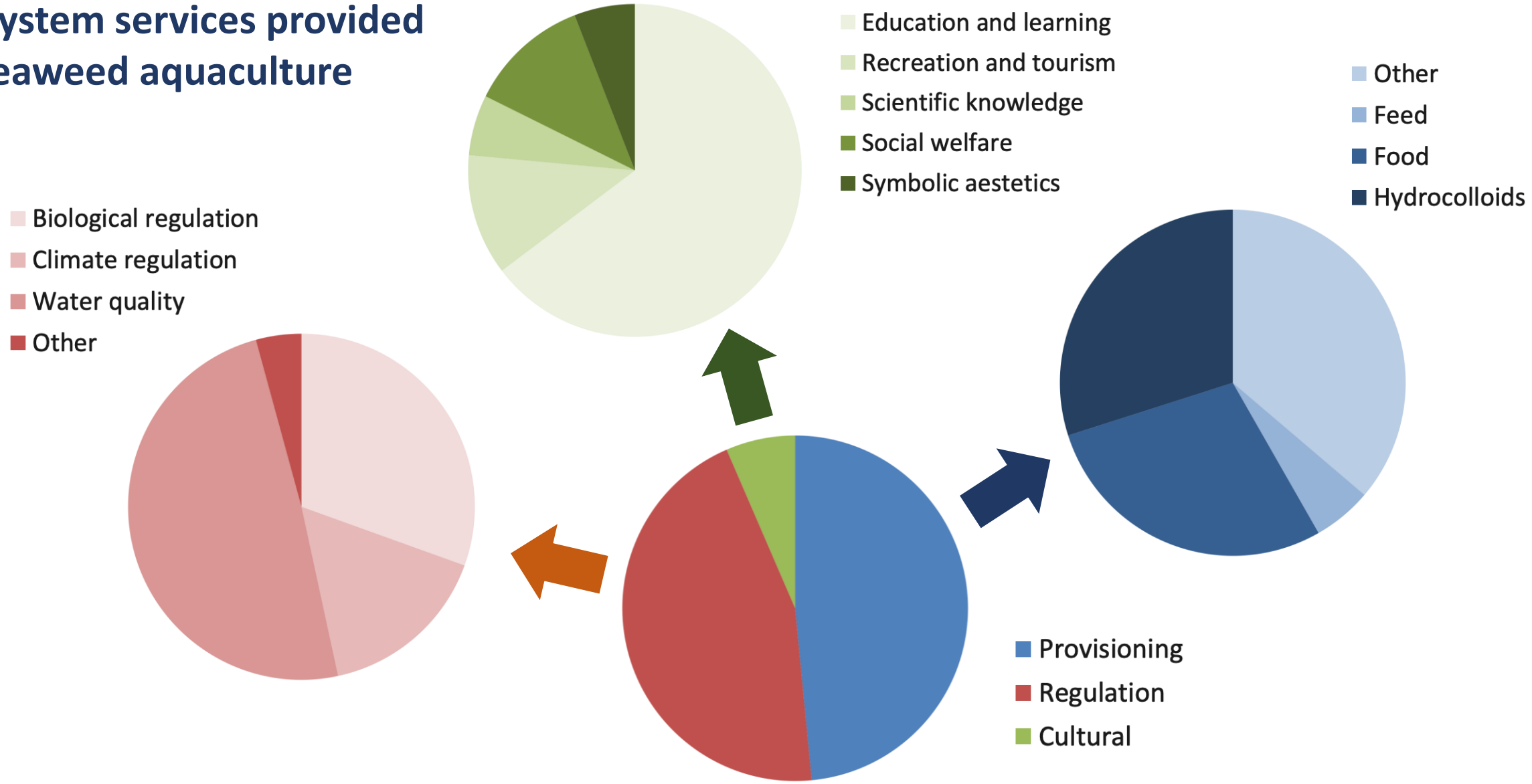
QSR results


Other
Porphyra/Pyropia
Euchematoids
Gracilarioids
Ulvales
Kelps

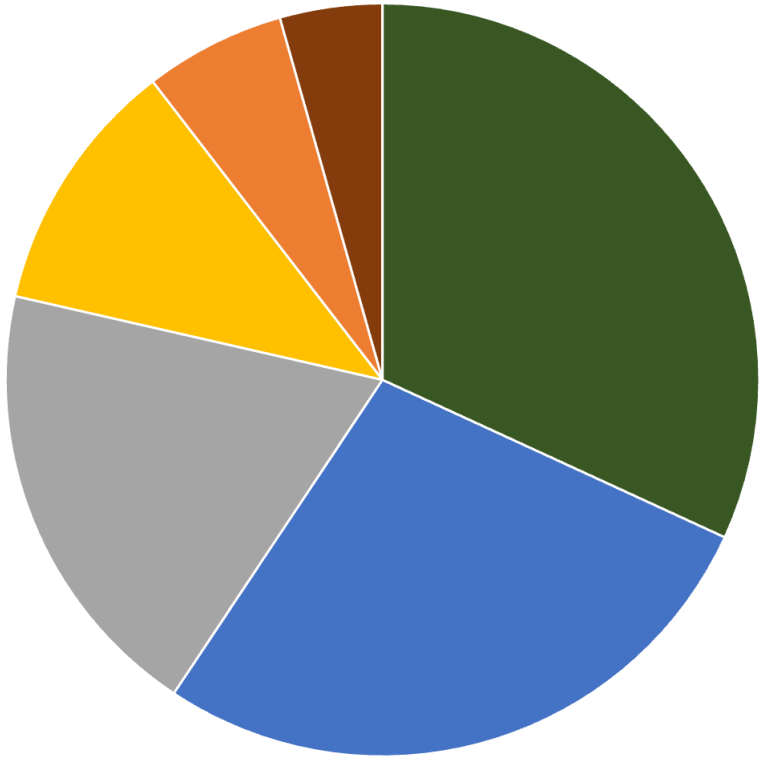

Land-based
Large scale
Small scale
No information
Near shore
Large scale
Small scale
No information
Offshore
Large scale
Small scale
No information
No information

QSR results

Ecosystem services provided by seaweed aquaculture

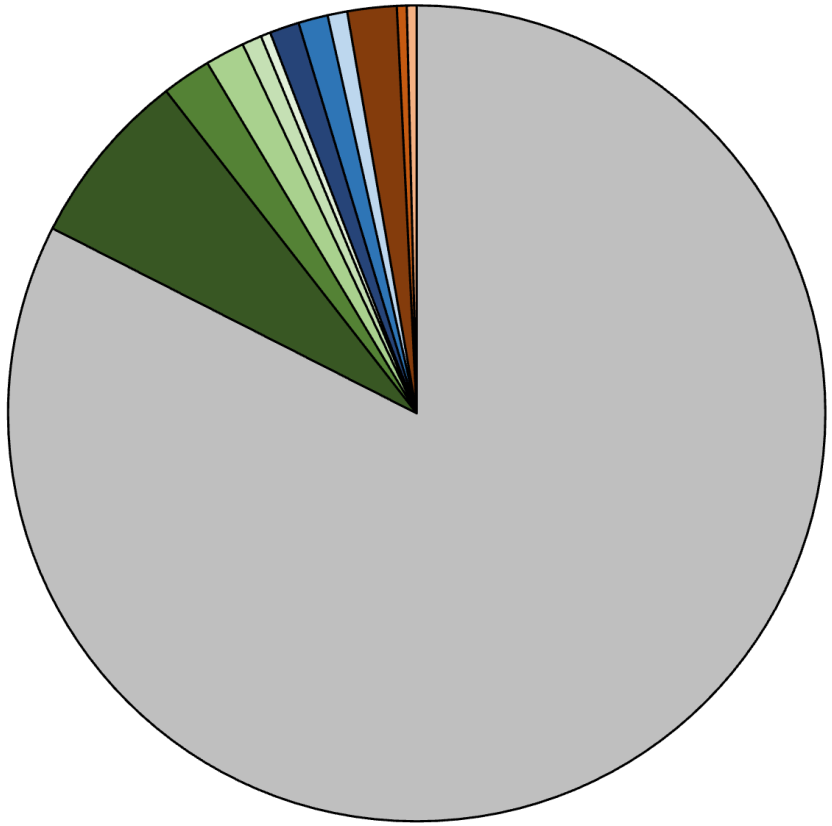


QSR results



CONSTRAINS

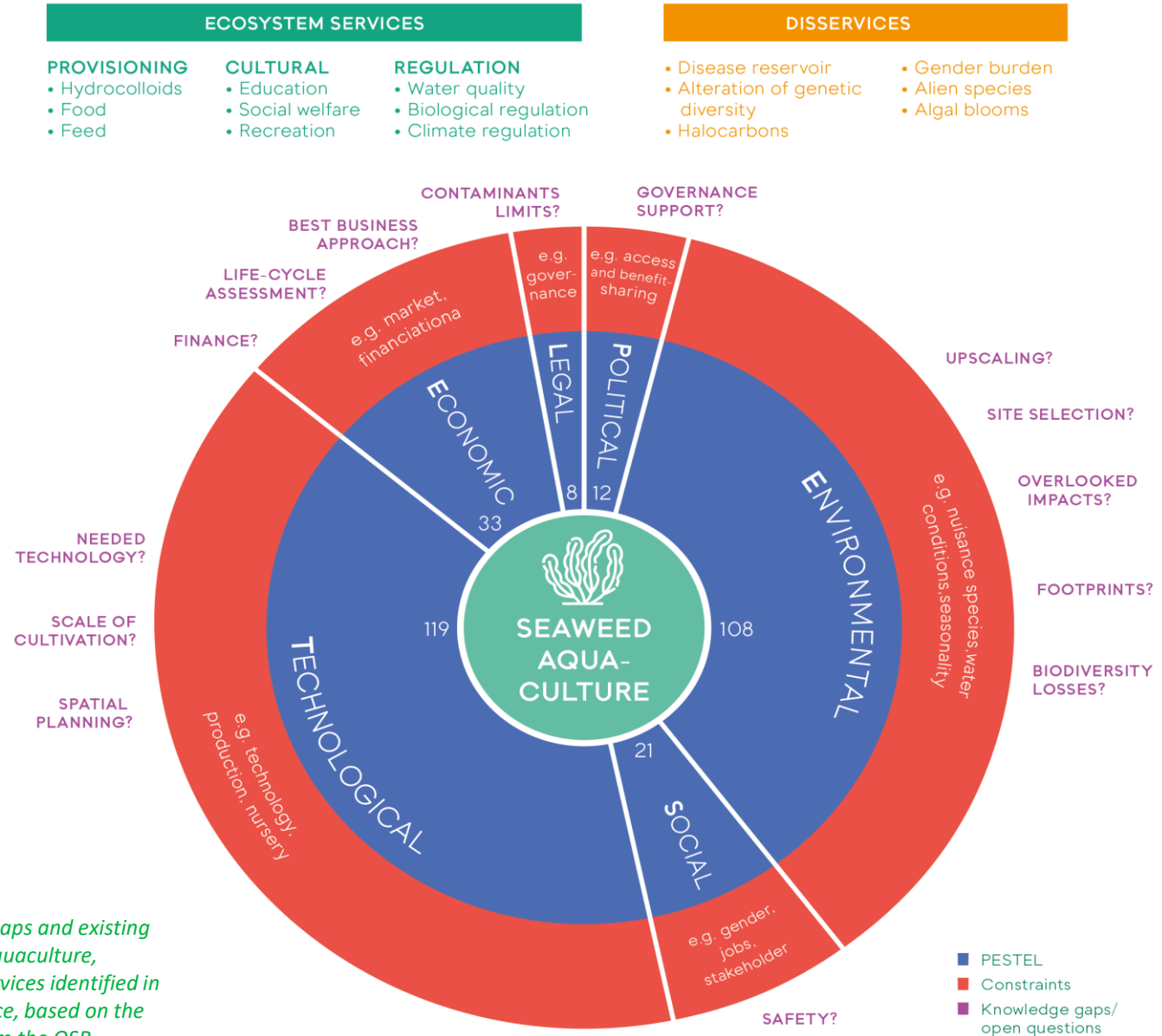
- Environmental
- Technical
- Methodological
- Economic
- Political
- Social



NEGATIVE IMPACTS

- Not investigated
- Algal blooms
- Impact on genetic diversity
- Biological diversity
- Diseases reservoir
- Biofouling
- Halocarbons
- Alteration on hydrodynamics
- Release o accumulation of pollutants
- Negative social impact
- Aesthetics
- Overexplotation

MAIN CONCLUSIONS



Conceptual model summarizing 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.

MAIN CONCLUSIONS

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?