WORKING GROUP 5

ULVA ECOSYSTEM SERVICES

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RATIONAL AND OBJECTIVES

The green seaweed Ulva is a cosmopolitan genus growing in all marine and brackish waters around the globe. Wherever the species grow, they provide ecosystem services (Haines-Young and Potschin 2017) or ecosystem disservices (Lyytimäki 2015) being part in the biogeochemical cycles of nutrients, carbon, sulphur and other mineral, affecting the composition of the surrounding water, the atmosphere and the associated biota. In balanced ecosystems, Ulva provides feed, shelter and oxygen for other marine organisms (Clemente and Thomsen 2024), whereas in eutrophic waters, Ulva grows out of control forming excessive mass blooms, also called green tides (Smetacek and Zingone 2013; Ye et al. 2011). In either case, the harvest of Ulva provides a biomass to be used for food, feed, biostimulants, materials and more (Bikker et al. 2016; Juul et al. 2024; Hofmann et al. 2025). Ulva can also be cultivated in systems both on land and in the sea, as a more controlled means of emission capture and utilisation – enabling the re-use of nutrients and carbon from waste streams or lost to sea .(Christiansen 2018; Larsen-Ledet et al. 2024; Mazarrasa et al. 2014; Sode et al. 2013; Zollmann et al. 2021; Neori 2008) The ecosystem services and disservices of Ulva species have yet not been fully described and mapped to gain sufficient knowledge to actively make use of the ecosystem services for improved environmental conditions and livelihood (Fricke et al. 2025).

WG5 has worked to increase and disseminate knowledge on Ulva ecosystem services and disservices, educate early carrier researchers in the concepts, potentials and methodologies of Ulva ecosystem services and disservices, and to formulate recommendations for policies strengthening the active applications of Ulva Ecosystem services in a European and global context.his will be used in Final Report).

ACTIVITIES AND KEY FINDINGS

The following activities have been carried out as part of WG5:

WG meetings (Knowledge transfer): 14 WG meetings have been accomplished with on-line participation of WG5 members. Here knowledge and research has been shared between group members.

Workshop (Knowledge transfer): A workshop was organised in Estonia in May 2024 in collaboration with WG6.

Training school (Knowledge transfer, carrier development): A training school was organised in Estonia in connection to the workshop with participation of XX early carrier scientists and SMEs.

Short Term Scientific Missions (STSM) (Knowledge transfer, carrier development): WG5 has supported a minimum of 4 STSMs, and connections have been made for transfers related to, but directly funded by, SeaWheat, i.e. as part of the SeaChem project (ECR from University of Galway to SME' PureAlgae (Denmark).

Publications (Knowledge creation): Several research papers connected to WG5 have been published by members of WG5. In addition, joint papers are in preparation based on the WG5 work: One systematic literature review summarising Ulva Ecosystem Services and Disservices (Deliverable D5.1a+b), one experimental research paper based on the WG5+6 training school in Estonia and one joint paper summarising the cost-benefits and life cycle assessment of harvesting Ulva for nature regeneration and provision of green protein (D5.1c). In addition to the peer reviewed publications published, submitted and in preparation for submission within 2025, three master thesis and one bachelor thesis have been finalised as part of WG5.

The WG5 MoU deliverable (5.1) has been achieved in the form of two joint peer-reviewed papers:

1. *Ulva Ecosystem Services - A Systematic literature review of the global ecosystem services and disservices of Ulva according to the CICES framework,* to be submitted to Science of the Total Enviroment. This paper summarises tasks 51.-5.4 and concludes the part a and b of the Deliverable 5.1:

a. **The providing and supporting ecosystem services of *Ulva* spp., nutrient and carbon removal and recycling.**
b. **The regulating services, the effect of biomass culture on reducing climate gas emissions and mitigating ocean acidification.**

The preliminary results show that Ulva species deliver Ecosystem Services around the globe with studies and descriptions from all continents and all climate zones. Most dominant are the Maintenance and regulation Ecosystem services with 'Filtration/storage/sequestration', 'bioremediation of toxic substances or waste', and 'Regulation of chemical conditions of salt water being the most dominant categories. However, also 'Regulation of chemical composition of atmosphere and ocean', 'Maintaining nursery (habitat, feed)', 'Control of erosion', 'Control of hydrological cycle', 'Pest control (incl. invasive species' and 'Disease controls' are among Maintenance and regulating ecosystem services described for Ulva. For the provisioning Ecosystem Services, provision of nutrition (food and feed) and materials dominated together with Materials, whereas energy was represented at a lower level. Here also demonstrating a movement with time in Ulva utilisation focus, from energy towards higher value such as nutrition. Regarding the cultural ecosystem services, Ulva was strongly represented under the 'Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge, as all registered studies represented the creasing of knowledge.

The review documents the importance and at the same time under-acknowledgement of Ulva Ecosystem Services and emphasises, the need for identifying, quantifying, acknowledging and valorising the Ulva Ecosystem Services to actively use them to support the UN SDGs (Duarte et al. 2022) and for progressing towards safe operating space within planetary boundaries (Richardson et al. 2023). The review paper is in preparation for submission, but has been presented at the International Seaweed Symposium in Victoria, British Columbia,Canada, May the 9th, 2025: **Abstract available on the SeaWheat website.**

2. *Towards Restorative and Regenerative Aquaculture: Sustainable Seaweed Production for Ecosystem Health and Blue Growth* to be submitted to Science of the Total Environment. This paper summarises tasks 5.5 and concludes the part c of the Deliverable 5.1:

c. **An economic cost-benefit analysis of biomass production and harvesting of Ulva spp. for ecosystem services**

This case study, situated within Denmark's scientific–industrial R&D landscape, investigated the dual benefits of protein extraction and water quality improvement, alongside climate change mitigation, through the gentle harvesting of Ulva spp., a green seaweed prevalent in green tide events. The biobased product–service system (BPSS) was evaluated using life cycle assessment (LCA) and net present value (NPV) methodologies to assess environmental sustainability and economic viability.

The LCA quantified the environmental impacts of harvesting and processing 1 ton of Ulva spp., under system boundaries that either included or excluded (i) emission capture and utilisation (ECU) of surplus aquatic nutrients and CO_2, and (ii) footprint savings from substitution. Scenario analysis compared the current Danish electricity mix with a future wind-powered energy system, covering climate change (CC), freshwater eutrophication (FE), marine eutrophication (ME), and land use (LU). Across scenarios, system-level footprints ranged from 124–145 kg CO_2 eq. (CC), 0.05–0.07 kg P eq. (FE), 0.006–0.007 kg N eq. (ME), and 3.8–8.4 m² (LU). Energy-related emissions accounted for only 15–20% of total GHGs, though the Danish mix was 38% more emission-intensive than wind. When ECU and substitution effects were included, the BPSS achieved net-negative footprints, ranging from –144 to –122 kg CO_2 eq. (CC), –0.36 to –0.34 kg P eq. (FE), –4.1 to –4.0 kg N eq. (ME), and –132 to –128 m² (LU).

Economic feasibility was assessed for two habitat restoration scenarios: harvesting 4.5 kilotons annually (base case) and 11 kilotons (extended case). Without revenues from environmental savings, NPVs were –0.6 million and 3.3 million €, respectively. Including environmental savings increased NPVs to 1.9 million and 10 million €, with payback periods of 3 years (base case) and 1 year (extended case). The rapid return on investment was driven by the availability of wild-harvested Ulva spp. from green tide events and the improved utilisation of processing capacity at scale, which together reduced the cost per tonne and enhanced overall economic performance.

The paper is submitted for publication and a **link is available on the SeaWheat website**.

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Directions and recommendations from WG5

1.Pave the way in legislation for expanding the use of Ulva cultivation to remediate nutrient rich waste streams or eutrofic waters with the dual goal of improving the quality of the marine environment contributing to meeting the targets of the EU Water Frame Directive, and providing a biomass to complement biomass produced on land.

2.Develop Food Grade certificates for Ulva cultivated in food system waste streams

3.Develop gentle harvest of Ulva green tides for improved environmental quality, avoided emissions of climate gasses and for providing biomass

4.Develop nutrient credit system to acknowledge companies cultivating or harvesting Ulva for regenerating ecosystem quality and providing an alternative biomass for the bioeconomic system

5.Limit nutrient emissions to coastal waters to reduce the Ecosystem Disservices of Ulva green tides globally, e.g. by cultivation of Ulva in waste streams prior to emission

Knowledge gaps:

1.Global extent of Ulva Green tides

2.Economic consequences of global Ulva green tides

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