# Emissions, capture, and utilisation: Principles and frameworks for Ulva

Kurresaare, Estonia

May 13-14, 2024

Ulva
The Future Wheat of the Sea

## ORGANIZERS

**Dr Annette Bruhn**, Aarhus University, WG5 leader
**Dr Celine Rebours**, Møreforsking, WG6 leader
**Dr Professor Georg Martin**, Estonian Marine Institute, local organiser

The COST Action SeaWheat (https://seawheatcost.haifa.ac.il/) and the research institutions, Estonian Marine Institute, Tartu University; Møreforsking and Aarhus University organized a 2-day Workshop on *Ulva* ecosystem services (WG5) and the regulatory aspects of *Ulva* ecosystem services (WG6), from May 13-14, 2024. The workshop was hosted by The Estonian Marine Institute at the GO Spa hotel in Kuressaare, Estonia.

## RATIONAL AND OBJECTIVES

The purpose of the workshop was to stimulate the interdisciplinary knowledge exchange and cooperation between experts from different fields of sciences from the academia and the industry. The common goal was to promote an up-scaled *Ulva* production as a means for providing Ecosystem Services, with specific focus on the removal and recycling of nutrient and carbon emissions, and documenting of the related effects of such aquaculture production on the environment.

Despite the use of *Ulva* for capture of nutrients in land-based aquaculture systems for decades, the methods to quantify the Ecosystem Services of *Ulva* (regulating and maintenance, provisioning and cultural) are under debate, and the regulatory frameworks for valorising and utilising the Ecosystem Services from seaweed aquaculture are still not in place.

The workshop was facilitated to bring together experts in *Ulva* production and ecophysiology, sustainability and regulatory frameworks, with the specific objectives to identify knowledge gaps and barriers, and to draft a common strategy to address and overcome those.

The outcome intends to be a significant contribution towards the overall goal of the 20106 COST ACTION SEAWHEAT project, which is to make a step-change towards a green economy based on *Ulva* mass production and utilization within the European community and beyond.

## ORGANIZATION

The workshop was part of the planned list of events for the current grant period, a joint organization between the leaders of WG5 and WG6, "*Ulva* Ecosystem Services" and "Social, legal and regulatory aspects", and the Estonian Marine Institute, where professor Georg Martin, Jack Hall and Kristina Tivel constituted the local organizing committee.

The Workshop program was discussed and decided among a group of experts that constituted the scientific committee. These were (listed alphabetically): Annette Bruhn (Denmark); Celine Rebours (Norway), Georg Martin (Estonia); Jack Hall (Estonia); Muki Shpigel (Israel); and Karel Keesmann (The Netherlands).

In addition to the organizing committee, it is also important to highlighting the role of the Social Media and dissemination group, in particular Karina Balina, who provided the graphical design of the abstract book and program, as well as she promoted the Workshop via all SeaWheat social media channels.

## PARTICIPANTS

The workshop was participated by 46 experts (3 of which presented online) from 19 different countries (Figure 31). Hereof, 43% of the participants were from ITC countries. Of the 46 participants, 13% were

affiliated to SMEs, 80% affiliated to Academic institutions and the final 7% were affiliated to other organizations. The gender balance between participants was 50-50 (Figure 32). The organizing committee prioritized physical attendance at the workshop to optimize the networking between attendants. For this reason, the works shop was not offered as a hybrid solution for on-line participants.

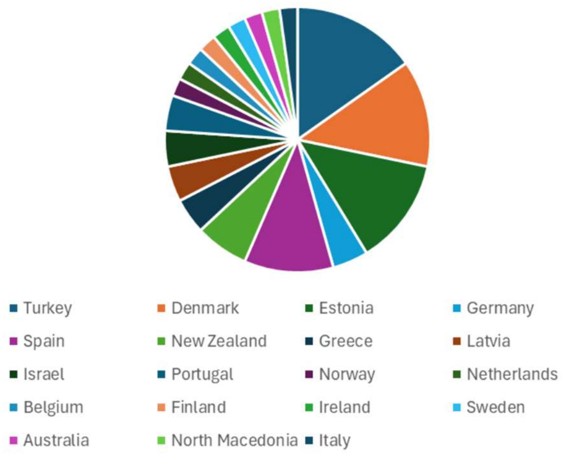


*Figure 31 Distribution of the workshop participants by country according to their affiliation*

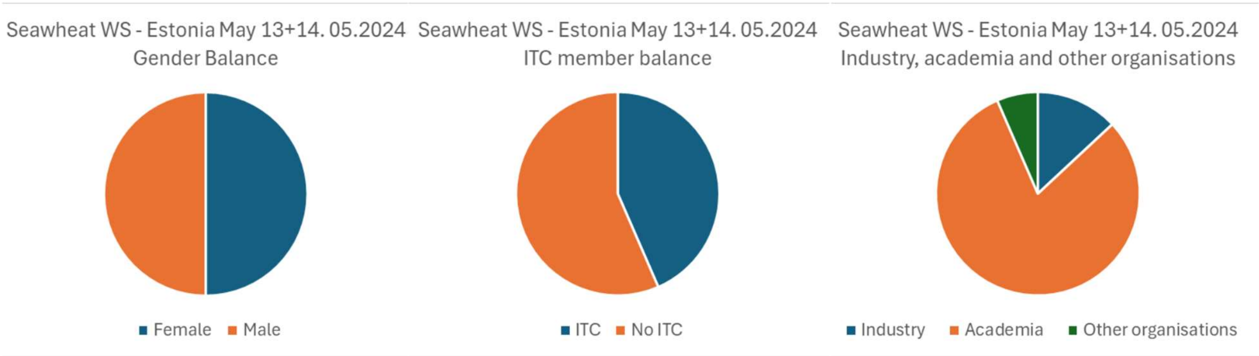


*Figure 32 Distribution of the Workshop participants by gender, members of ITC countries and affiliation*

*Figure 33 Group photo of the participants of the Seawheat workshop outside the venue, the GO Spa hotel, Kuressaare, Estonia*

## WORKSHOP DESIGN AND FUNCTIONING

The workshop was designed to include presentation arranged in three sessions by topic, including 30-60 minutes for discussion of each topic by the end of each session, and an industry visit to the hydrocolloid factory, Estagar, producing furcellaran from the local *Furcellaria lumbricalis*, and the land-based trout producing company, Ösel Harvest OÜ, in cooperation with which, the Estonian Marine Institute has installed a test facility for *Ulva* production for investigating and optimizing the emission capture of nutrients and CO2 from the fish production.

In summary, there were 15 presentations, divided into 3 presentation sessions with discussions. Topics covered during the sessions, in line with WG5 and WG6 and decided by the scientific committee were: Session *1 – Algae production policy and regulatory settings; Session 2 – Quantifying emission capture – challenges and valorisation; and Session 3 – Environmental accounting (Ecosystem services & LifeCycle Assessment) challenges of applying to seaweeds*. For more details on the program, please see Annex I at the end of this report.

Each session comprised between 3-6 presentations and included 30-60 minutes for discussion of the correspondent topic. A total of 15 talks, including 3 keynote talks by our international guest speakers (Dr Catriona Hurd from Australia, Maris Stulgis from the EU commission and Kátlin Aun from Estonia) set the stage for the discussion moments. Also relevant to note the role of the session chairs. Each session had 1 designated chair, with the mission to a) keep time and moderate the discussions during the presentation moments and b) animate and moderate the discussions during the discussion sessions for each topic.

Prior to the beginning of the workshop, the designated Session Chairs received an information package for their session, including a short-bio of each of the speakers as well as the abstracts for each presentation.

Finally, last but not least, the workshop offered time and opportunity for networking between the participants. The participants were taken on a guided tour to visit two local companies: First to the Estagar production facilities, where Dr Mart Mere (Co-owner and development leader) explained the function of the entire site, the technologies involved, and the capacities of the site. Following the WS participants visited the land-based trout production company, Ösel Harvest OÜ, where Henry Ots gave a full tour of the production facility, and Dr. Professor Georg Martin and Jack Hall introduced the participants to the experimental work of using Ulva for bioremediation of the fish farm effluents.

Networking was also very intensive, stimulating and fruitful between sessions and during the dining and cultural events, emphasizing the benefits of physical meetings between participants from science and industry.


*Figure 34 Different moments of the workshop: presentations, part of organizing team and networking*

*Figure 35 Industrial site visits - trout farm and EstAgar*

*Figure 36 Local culture moments of the WS - Kuresaare Castle, the Kaali crater and dining at the historical wind mill restaurant*

## CONCLUSIONS

The workshop “Emission capture and utilization – principles and frameworks for Ulva” was a very enriching event for all participants, judging from the engaged discussions, the networking between sessions and from the feedback of the participants at the end of the event. A proceedings of the work shop is under preparation in the form a special issue of the peer-reviewed journal Botanica Marina (impact factor: 2.2), where presenters and participants can submit their presentations or related scientific work for peer-review.

The organizing committee has a strong impression that the objectives of the workshop were attained, as interdisciplinary knowledge exchange was achieved between experts from different fields of sciences and from academia and industry, and future cooperations were stimulated. A common understanding, across standing points, of the challenges of quantifying and documenting the ecosystem services of seaweeds, and particularly Ulva, with focus on the removal and cycling of nutrients and carbon through aquaculture, was taking form, emphasizing the need for interdisciplinarity for fully meeting the targets of environmental, economic and societal benefits of a future up-scaled Ulva production.

In terms of the specific objectives defined, the discussion sessions resulted in information regarding “Challenges and Barriers” and “Proposals for solutions” in all discussion topics (Annex II).

# Emissions, capture, and utilisation: Principles and frameworks for Ulva

Kurresaare, Estonia

# PROCEEDINGS

Ulva
The Future Wheat of the Sea

This abstract book compiles all the work presented by the speakers and poster presenters at the Seawheat workshop: **'Emissions, Capture, and Utilisation: Principles and Frameworks for *Ulva*'** organized by WG5 and WG6 in Kuressaare, Estonia, during the 13-14th of May 2024.
The purpose of the workshop is to stimulate the interdisciplinary knowledge exchange and cooperation between experts from different fields of sciences from the academia and the industry. The common goal is promote an up-scaled *Ulva* production as a means for providing Ecosystem Services, with specific focus on the removal and recycling of nutrient and carbon emissions, and documenting of the related effects of such aquaculture production on the environment. Despite the use of *Ulva* for capture of nutrients in land-based aquaculture systems for decades, the methods to quantify the Ecosystem Services of *Ulva* (regulating and maintenance, provisioning and cultural) are under debate, and the regulatory frameworks for valorising and utilising the Ecosystem Services from seaweed aquaculture are still not in place.
The workshop facilitates to bring together experts in *Ulva* production and ecophysiology, sustainability and regulatory frameworks, with the specific objectives to identify knowledge gaps and barriers, and to draft a common strategy to address and overcome those. The outcome intends to be a significant contribution towards the overall goal of the SEAWHEAT COST Action (CA20106), which is to make a step-change towards a green economy based on *Ulva* mass production and utilization within the European community and beyond.
The venue of the event has been chosen to widen the geographical coverage of the experts dealing with *Ulva* cultivation as the northern Baltic Sea region represents somewhat harsh conditions for *Ulva* species to thrive (low salinity, seasonality, ice conditions). The host institution, Estonian Marine Institute, is a recognised centre of Baltic Sea research doing its first steps in low trophic aquaculture research.
The abstracts are organized in their order of presentation at the workshop.

# EUROPEAN COMMISSION'S SUPPORT TO EU ALGAE SECTOR DEVELOPMENTS

Maris Stulgis[1]*

[1]Policy Officer, European Commission, DG Maritime Affairs and Fisheries (DG MARE)

In recent years, European Commission has increased its support to the algae sector developments in the EU. Based on the gap analysis done Commission has come up with a 23 policy actions plan for the EU in a form of the EU Algae Initiative. More and more algae-related project acquire EU funding, ‘’algae” is appearing in more and more new or existing EU policies as an emerging opportunity, more and more investors and businesses are turning towards algae based businesses. To boost the collaboration within the EU algae sector, an EU4Algae – European Algae Stakeholder Platform (with 900+ registered members) has been launched. During the presentation you will learn about these and other EU actions and future plans in supporting EU algae sector.

# REGULATIONS AND POLICIES FOR THE *ULVA* PRODUCTION: IMPORTANCE OF RRI, CONVENTION OF BIOLOGICAL DIVERSITY, NAGOYA PROTOCOL, ACCESS AND BENEFIT SHARING CLEARING HOUSE.

Céline Rebours[1]*

[1]Møreforsking AS, Norway

Blue Biotechnology (BB) is a multidisciplinary, knowledge- and capital-intensive technological area that significantly contributes to innovations in the pharmaceutical, medical, cosmeceutical, nutraceutical, aquacultural, agricultural, and energy sectors. The BB sector in Europe includes non-traditionally commercially exploited marine organisms and their biomass applications. Seaweeds are identified as one of the more valuable sources of structurally diverse bioactive compounds among the marine organisms, and their utilization would support society to gain various health benefits. Seaweed cultivation in Europe is still in its early stages, with a main emphasis on kelp species. These species face challenges in penetrating the market, calling for a need to diversify the cultivated species. The food and feed sectors (i.e. human food, food supplements, nutraceuticals, animal feed) are the main markets for macroalgae biomass (up to 60%) in Europe, with other minor applications being cosmetics (18%) and fertilisers and biostimulants (11%)[1]. The green species of the genus *Ulva* can effectively assimilate dissolved nutrients with high efficiency and biomass yield[2]. Only a limited number of *Ulva* species are currently cultivated on a pilot scale, predominantly in land-based systems, and in some cases under IMTA systems[3]. In northern Europe, high biomass yields in land-based systems have been demonstrated with *Ulva* biomass that can be valorized as food and feed ingredient[4]. As the quest for marine-derived compounds with pharmacological and biotechnological potential upsurges, the importance of following regulations and applying Responsible Research and Innovation (RRI) principles also increases. This presentation aims at: 1) presenting important regulations and policies that apply to the *Ulva* production at the EU level; 2) highlighting the importance of the application of the RRI principles in biodiscovery, and 3) identifying gaps and providing recommendations on how to improve compliance of novel BB compounds with guidelines on ethical and benefit-sharing of genetic resources.

References 1. Vázquez Calderón and Sánchez López 2022 Publications Office of the EU, Luxembourg, ISBN 978-92-76-54516-3. 2. Lubsch and Timmermans 2018 J Phycol. 54(2) :215-223. 3. Neori et al. 2003 J Appl Phycol. 15(6) :543-553

# FRAMING THE ECOSYSTEM SERVICES OF ULVA

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Green macroalgae species belonging to the *Ulva* genus provide a range of ecosystem services (ESS) worldwide – categorised as ‘regulation and maintenance’, ‘provisioning’ and ‘cultural’ ESS, adapting the Common International Classification of Ecosystem Services (2018). The ESS derive from 1) *Ulva* being part of natural balanced ecosystems, 2) *Ulva* being harvested and removed from unbalanced ecosystems and 3) *Ulva* being cultivated as a bioresource, and/or as a mitigation or restorative ecological engineering tool capturing and utilising carbon and nutrients. The ESS provided all contribute to achieving several UN Sustainable Development Goals – directly and in an integrative manner of which SDG 3, 6, 12, 13, 14 and 15 are closely related to the planetary boundaries quantifying the ecological ceiling of the safe operating space of humanity. In natural ecosystems, *Ulva* provides regulation and maintenance ESS such as photosynthesis, nutrient cycling, food and habitat. *Ulva* harvested from unbalanced ecosystems along with the cultivated *Ulva* allow for bringing into play the regulation and maintenance ESS as mitigation or restorative ecological engineering tools capturing and utilising carbon and nutrients, while providing a bioresource for food, feed, nutraceuticals and fibres. Cultural ESS are provided by *Ulva* through contribution to science and education.

## EU STANDARDIZATION ON ALGAE AND ALGAE PRODUCTS

Susan Løvstad Holdt[1,2,3]*

[1]DTU Food

[2]The National Food Institute

[3]Technical University of Denmark.

The markets of algae are increasing, and European Commission realized that we need to know what we are trading; how do we know what we are trading and how we describe it? The challenges are e.g.:

- The green flakes that we say is Ulva, how was that species identified?
- The protein content of 12% how was that analysed and calculated?
- What unit do we use on productivity and emission capturing, and can we compare to other crops?

A group of experts across EU from companies and research work on standardizing definitions, sampling, analyses on nitrogen, amino acids, sugars, lipids, fatty acids, for cosmetic use and also energy purpose. Using the standards are not mandatory, but ensuring that the best methods are sed and a "license to trade". We know that when e.g. companies refer to that the laboratories are working according to ISO standard ## that optimized procedures are implemented. This presentation will introduce a selection of relevant standards and standards being developed that are of interest for *Ulva* and its applications.

# NOVEL DPSIR FRAMEWORK WITH THE ECOSYSTEM SERVICES APPROACH FOR SEAWEED PRODUCTION: FROM PRESSURE TO PROGRESS AND FROM REDUCE TO RESTORE

Thomsen, M.[1,2], Ecole, M.[1,2], Anwar, I.[1,2], Bruhn, A.[3,4]

The emerging seaweed aquaculture in Europe and Americas is expanding, delivering system value from engineered ecosystem services (EES) such as eutrophication and climate change mitigation. The use of seaweed as a nature-based emission capture and utilisation technology turning emissions into revenue streams while delivering non-profit value makes seaweed aquaculture a promising eco-industrial system fitting well the global agenda of green economic transitions and ecosystem health restoration. However, aquaculture activities may in some cases cause unwanted engineered ecosystem disservices (EDS), which should be avoided. For this reason, we propose an emission accounting and ecosystem-based framework with an extended scope I and IV to include circular nutrient management in the biobased product service system starting at scope I (emission capture), through scope II (energy-related emissions associated to the operation of the aquacultural production system), to the scope III, including material consumption and avoided emissions from transitioning into a biobased economy) and ending at scope (IV) which the potential services (or disservices) by the seaweed aquaculture. The emission accounting and ecosystem-based framework consisting of a triadic interrelationship between academia, industry and government with the common objective of implementing a sustainable blue economy delivering provisional (biorefinery products), supporting (nutrient recycling), and regulating (climate change mitigation) services, thereby restoring the balance between marine ecological integrity and ecosystem service utilization. We argue that an adaptive and cross-sectoral policy framework approach, with coordinated instruments, is imperative to a design of blue circular bioeconomy, from primary production to final output products (i.e. phyconomy), that restores, regenerates and respects the carrying capacity of our aquatic ecosystems. A novel DPSIR framework is presented that shifts from focusing on reducing pressure to making progress towards a restorative blue economy, emphasizing the integration of the ecosystem-based monitoring and reporting system which enables multi-governance actors from institutions across the involved sectors and scales to collaboratively develop a blue bioeconomy that delivers engineered ecosystem services that contributes to the restoration of marine ecological integrity.

## HOW TO TURN EMISSIONS INTO REVENUE STREAMS

Esben Rimi Christiansen[1]*

[1]Founder of Pure Algae

Scarcity of resources increase while linear nutrient flows from land to sea contribute to marine eutrophication, and consequently loss of biodiversity. It is imperative to change the linear nutrient flows from land to sea into circular nutrient flows in order to conserve bioavailable nitrogen and phosphorus in the technosphere. Land-based fish production in recirculated aquaculture systems (RAS) provide opportunities to capture and utilise emissions of nutrients and CO2 for cultivation of macroalgae in Integrated Multitrophic RAS (IMRAS). Hereby emissions are turned into revenue streams generating a double crop production, while alleviating the biosphere from negative impacts of nutrient and CO2 emissions. *Ulva* – opportunistic green macroalgae, grows explosively under favourable conditions, generates high biomass production, and are attractive for European and global food and feed markets. Pure Algae has found a unique method and developed a technology for increasing the yield and bioremediation capacity of *Ulva* (figure 1) and keep this process stable over a long period of time (figure 2), while monitoring the quality of the seaweed as a result herof (figure 3) Results prove that *Ulva* biomass can be produced in high output and high quality when integrating a vertical seaweed cultivation system into the RAS industry.

# SEAWEED SUSTAINABLE FARMING: THE EXAMPLE FROM AN EU ORGANIC CERTIFIED PRODUCER

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Aquaculture has been mentioned as a solution to the exponential population growth, but the conventional methods of finfish effluent treatment are complex and expensive. Cultivation of seaweed, responsible for more than 40 ton of nitrogen removal from coastal waters, seems to be a solution in the mitigation of environmental impact of finfish aquaculture. IMTA systems are a combination of these: they consist in the incorporation of different trophic levels on the same system in a balanced ecosystem, where finfish nutrient-rich effluents are used by the other species, converting waste into valuable commercial crops. Since 2012, ALGAplus, a Portuguese company located in Ria de Aveiro, dedicates to organic certified Atlantic seaweed species and fish farming in a land-based IMTA system. All seaweed production phases are carried out in-house: biomass production, processing and packaging. Besides, ALGAplus works with their customers on tuning the seaweed biomass to the desired characteristics or on the domestication of new species of interest. Nowadays, the main species in production is *Ulva sp.*, but species as Porphyra spp., Gracilaria gracilis, Codium tomentosum are also farmed year-round. With a strong focus in R&D, in 2023, AlGAplus reached an annual production of 210 ton (fw) of *Ulva* with the new 15 raceways-unit, designed in the frame of the European project GENIALG. Currently optimizing the system in terms of energy and labor costs and manipulation of production factors, the company is tackling these keystone tasks in the frame of different collaborative projects, such as SeaMarK (Horizon Europe) and Pacto da Bioeconomia Azul (02/C05-i01/2022).

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## QUANTIFICATION OF CARBON DIOXIDE REMOVAL AND CARBON SEQUESTRATION BY SEAWEED

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Seaweeds are an extremely important marine resource in coastal systems globally, with substantial potential for human food, feed additives, methane reduction from ruminants and novel products. Increasing seaweed stocks, particularly via aquaculture including into the open ocean, has been widely promoted as a natural, safe and simple solution to climate change via the photosynthetic fixation of atmospheric carbon dioxide and the subsequent sequestration of carbon as living biomass or into sediments:seaweed carbon credits are being sold on the voluntary carbon market on this basis. However, the optimism and enthusiasm afforded by seaweed ‘afforestation’ for carbon dioxide removal (CDR) is not currently supported by underpinning science. Here I consider how a very complex solution for CDR has gained such popularity, then outline best scientific practices required to assess CDR by seaweeds using a Forensic Carbon Accounting framework.

## GROUNDING THE HYPE AROUND CARBON REMOVALS WITH SYSTEMS THINKING, AND LCA PRIORITIES TO SUPPORT A MORE SUSTAINABLE BLUE ECONOMY

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Have you noticed that over the past year, we aren't seeing quite as many headlines claiming that seaweed is a silver bullet to solve the climate crisis? Confidence in this rhetoric has been undermined, and no one seems sure that climate benefits through carbon credits, removals and offsets is trustworthy anymore. In an attempt to restore trust and guarantee climate benefits, the EU is developing the carbon removal certification framework and the associated Qu.A.L.Ity criteria, and green claims may soon also be regulated. So how will this affect the algae sector? During this talk, we will explore the role of systems thinking and life cycle assessment (LCA) in grounding the hype around carbon offsets/removals, in shedding light on the environmental performance of seaweed value chains, the current state of LCA research in the sector, and what we urgently need to focus on. A critical review of the life cycle climate impacts of seaweed value chains is presented, providing a systems perspective to complement ongoing primary research that is being undertaken. LCAs strengths and weaknesses as a methodology are discussed in the context of seaweed and marine value chains, and priorities are suggested for how to evolve the method and improve its practice to better serve the growth of a sustainable blue economy.

# SEAWEED CULTIVATION OR BEACH WRACK HARVESTING AS A MEASURE FOR NUTRIENT UPTAKE – A POSSIBLE BASE FOR FUTURE NUTRIENT TRADING SYSTEMS IN THE BALTIC SEA?

Fredrik Gröndahl[1,2,3]*

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The Baltic Sea's low salinity means that both animals and plants invest a lot of energy in internal salinity regulation, which means that they are smaller than their relatives in a saltier sea area like the Skagerrak. Thus, when establishing a maritime aquaculture in the Baltic Sea by e.g. cultivation of blue mussels or seaweeds (Ulva), the individuals will be smaller and not economically competitive compared to their more maritime and bigger relatives from high salinity sea areas, especially if they are to be used for profitable food production. Thus, the concept of environmental mussel or environmental seaweeds has been introduced where it is argued for the cultivation of these for the uptake of fertilizing substances such as nitrogen or phosphorus from the eutrophic marine environment in the Baltic Sea. A cheaper alternative to the cultivation of seaweeds could be to take advantage of the enormous amounts of seaweed biomass washed up on the shores of the Baltic Sea as beach wracks (casts) and then use the biomass for e.g. biogas production or land-based fertilizer. The result is the same, remediation of nutrients from the Baltic Sea. The question is whether this harvest of biomass, which generates a positive effect for the environment and currently does not have a market price, should be subsidized with some form of market-based support from society. This paper/talk will discuss payments for nutrient uptake in the blue bioeconomy and when its well-motivated and when we should be careful to use it.

# ECOSYSTEM ACCOUNTS IN ENVIRONMENTAL ECONOMIC ACCOUNTING – IMPLEMENTATION EXPERIENCE IN ESTONIA

Kätlin Aun[1]*

[1]Statistics Estonia

In recent years ecosystem accounting has seen a lot of development. UN Statistical Commission adopted System of Environmental-Economic Accounting - Ecosystem Accounting (UN SEEA EA) in 2021. The amendment of Regulation (EU) No 691/2011 is ongoing to include ecosystem accounts as one of the modules. More and more research is done on the topic which contributes to the better understanding of the concepts and application. Statistics Estonia began work first with ecosystem extent and monetary values in year 2019 following the guidance in SEEA EEA (EEA Ecosystem Experimental Accounting) and available country experiences. During the years the work has shifted to include physical ecosystem service flows and ecosystem condition indicators according to the amendment of Regulation (EU) No 691/2011. The presentation gives an overview of ecosystem accounts in environmental economic accounting system and describes Statistics Estonia's experience in ecosystem accounting. The work done includes mainly terrestrial ecosystems but the experience of mapping marine ecosystems and the concept of (marine) thematic accounts is also discussed.

## EU4ALGAE IN ACTION – ANALYSING BIOREMEDIATION POTENTIAL OF ALGAE

Efthalia Arvaniti[1]*

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EU4Algae Stakeholder Forum is the first implementation action of the EU4Algae Initiative. The ongoing work on ES aims to assess available tools methods and scenarios for quantifying bioremediation services, including disservices of production, set state of play on environmental carrying capacity, and make suggestion towards further designing a monitoring framework. The work includes macroalgae cultivation both at sea and on land, as well as microalgae. In this session, Efthalia will present current work done and next steps, and take the opportunity to gather and share insights and recommendations to include in the upcoming publications.

# INTEGRATING *ULVA* INTO IMTA SYSTEMS FOR ENHANCED NITROGEN BUDGETS AND ECOSYSTEM SERVICES

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The scarcity of freshwater, overfishing and declining ocean biodiversity, marine eutrophication by anthropogenic activities, and the increasing demand for seafood have all required attention from a more comprehensive, global perspective.Moving from conventional aquaculture toward an ecological approach to developing and managing a sustainable aquaculture that cares for environmental and sociological aspects can bring relief to at least some of these problematic issues. Nutrient removal using Integrated Multi-Trophic Aquaculture (IMTA) systems is a promising ecological approach for sustainable aquaculture. The rationale behind the IMTA systems is to convert the excretions of the organisms cultured upstream into valuable food for the organisms cultured downstream. In marine IMTA systems, algae and halophyte plants have a high capacity for nutrient uptake per unit of culture area and can be an essential additional valuable product. In addition to nutrient removal by the green seaweed *Ulva sp.*, the IMTA system proved to be a reliable source of sustainable biomass for human consumption, animal feed, and high-value by-products for the food additive industries. IMTA systems in offshore cage cultures and land-based facilities will improve the food conversion rate (FCR) and diversify the mariculture products, ultimately increasing profit for the farmer. In addition, they will often create additional jobs and, no less importantly, will reduce environmental pollution.

## MODELLING AND IDENTIFICATION IN AQUACULTURE

Karel J Keesman[1]*

[1]Mathematical and Statistical Methods – Biometris, Wageningen University

Mathematical models are crucial in many scientific fields. Nowadays, computer-aided model simulations are used more and more to support (i) the understanding of the dynamic behavior of water, nutrients and energy flows in food (Ulva) production processes and (ii) the design, optimization and control of reactors and reactor networks in these technological applications. Mathematical modelling that starts from first principles can be a good start. For operational use in real practice, however, the model should be in good accordance with experimental data, which is the main objective of system identification. Yet, in the past decade data-driven modelling approaches become more and more popular, thus using a limited amount of prior knowledge. However, for understanding and design of new (production) processes the use of prior knowledge, in terms of mass and energy balances, is of paramount importance.