
Baltic
MUPPETS

DELIVERABLE 1.7

REPORT ON DIGITAL MAPS

Co-funded by
the European Union

Disclaimer: Baltic MUPPETS is co-funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the granting authority, European Innovation Council and SMEs Executive Agency (EISMEA). Neither the European Union nor the granting authority can be held responsible for them.

Grant agreement number	101083785
Project title	Baltic MUPPETS Baltic MUssel Products for PET-foodS
Deliverable title	Report on Digital Maps
Deliverable number	1.7
Deliverable version	1
Contractual date of delivery	30/06/2024
Actual date of delivery	
Document status	Final
Online access	To be published on Baltic MUPPETS website
Diffusion	Public
Nature of deliverable	RE- Document, Report
Work Package	1
Contributing partners	UTARTU
Author	Jonne Kotta (UTARTU), Merli Rätsep (UTARTU), Mihhail Fetissov (UTARTU)
Editor	Reviewed by Peter Krost (CRM), Lidia Lins Pereira (SUB)
Keywords	Low-trophic Aquaculture, Mussel growth, Digital tool, Baltic Sea

TABLE OF CONTENTS

Co-funded by the European Union

EXECUTIVE SUMMARY

Baltic MUPPETS is a three-year initiative supported by the Interregional Innovation Investment (I3) instrument. The project aims to create a new value chain for small bivalve molluscs in the Baltic Sea region by developing nutritious and high-quality pet food products. It will focus on investing in innovative techniques for underwater cultivation, harvesting and processing of the Baltic Sea's native blue mussel. This initiative is expected to support local economic development and increase quality employment opportunities. In addition, mussel farming is expected to provide several ecosystem services such as nutrient removal, water quality improvement and biodiversity enhancement.

This document describes Deliverable 1.7 of the Baltic MUPPETS project, which focuses on digital maps. It outlines the workflow for the development of digital maps, including the definition of the modelling domain and model type, the development of the model and the production of the maps. These maps are important tools for spatial planning within the Maritime Spatial Planning process, the selection of sites for new mussel farms and the strategic expansion of mussel farming. This will ensure the economic viability of shellfish production without compromising the environmental sustainability of the region. As a result, the document provides essential insights for developing new business cases and expanding existing operations in mussel production throughout the Baltic Sea region.

1. INTRODUCTION

Aquaculture plays a central role in the EU's Blue Growth Strategy (EC, 2012) and has both positive and negative impacts on water quality. As the fastest growing sector of food production, aquaculture accounted for 56% of the global supply of fish, crustaceans and molluscs in 2020 and by 2030, aquatic food production is expected to grow by an additional 15% (OECD/FAO, 2021; FAO, 2022). Marine bivalves such as mussels, oysters and clams, which are classified as extractive species, serve as natural nutrient sinks. These filter feeders clean the water by absorbing particles suspended in the water column. In particular, the harvesting of cultured bivalves effectively removes nitrogen (N) and phosphorus (P), thereby improving the water quality of surrounding areas (Carlsson et al., 2012; Kraufvelin & Díaz, 2015; Kotta et al., 2020).

In addition, shellfish aquaculture contributes to nutrient cycling and recycling. Traditional internal eutrophication control measures, such as oxygenation of bottom waters to alter sediment redox conditions and bind phosphorus to iron (Stigebrandt et al., 2015) or treatment with aluminium to immobilise phosphorus in sediments (Rydin et al., 2017), prevent phosphorus from being reused. In contrast, the harvesting of biomass from aquaculture, particularly farmed mussels, allows for an effective recirculation of nutrients from the sea back to land (Buer et al., 2020; Kotta et al., 2020). These harvested mussels are not only used for human consumption (Gren et al., 2009), but also for the production of poultry and animal or pet food (McLaughlan et al., 2014; Vidakovic et al., 2016; Bertilius & Vidakovic, 2019; the Baltic MUPPETS project). In addition, they can be processed into bioenergy (Hu et al., 2011; Nkemka & Murto, 2013) or used as soil amendments, demonstrating their versatility and ecological benefits.

The Baltic Blue Mussel is a marine species group characterised by a specific genetic hybridisation between *Mytilus edulis* and *M. trossulus* (Stuckas et al., 2009; Kijewski et al., 2019). These mussels are able to survive in salinities as low as 4-5. However, their growth decreases at lower salinities due to increased energy requirements for osmoregulation (Maar et al., 2015), and they show improved growth at higher salinities (Buer et al., 2020; Kotta et al., 2020). As primary consumers, mussels are often a keystone species in their ecosystems, dominating in terms of abundance and biomass. They provide a variety of valuable ecosystem services, including enhancing water clarity, sequestering excess nutrients, improving the ecological condition of benthic habitats, and serving as a food and habitat source for a variety of species at different trophic levels. In addition, these mussels are important as a source of animal feed and human food. While harvesting mussels in their natural environment poses environmental risks, their cultivation offers a sustainable and regenerative aquaculture alternative. Promoting shellfish farming can enhance coastal ecosystems, promote the sustainable blue bioeconomy and diversify coastal economic activities.

Blue mussel aquaculture depends on the capture of free-swimming larvae (veligers) from wild populations. These veligers enter the water column and are passively dispersed away from natural mussel beds. Once dispersed, the veligers attach themselves to suitable substrates, often within existing mussel beds. Identifying optimal sites for mussel farming therefore requires an understanding of the connectivity between potential farm sites and natural mussel reefs to ensure that areas can support mussel growth without the need for artificial seeding (Kotta et al., 2020).

In order to select and expand mussel farming areas in the Baltic Sea region, it is important to identify sites that are conducive to mussel cultivation and to secure areas that are suitable for sustainable growth. Ecological process modelling plays an important role in this effort by identifying productive sites, predicting area-specific production yields and determining environmental carrying capacity, thus guiding optimal farm expansion. This approach prevents nutrient depletion and mitigates potential environmental impacts. Such analytical models are essential for maximising production yields while respecting the ecological limits of the environment. In addition, when validated with data from local farms, these models provide accurate assessments of the nutrient and carbon sequestration and recycling capabilities of mussel farms, supporting various sustainability and climate change mitigation objectives. The aim of this report is to give an overview about the development of digital tool for spatial planning and site selection of new mussel farms, which also serve as a valuable input for the preparation of business cases for mussel production in the Baltic Sea region. This tool explores different spatial configurations of farms and incorporates different farming technologies, as dictated by the input parameters set within the tool. The outputs of this tool are digital maps designed for direct use by end users.

To effectively communicate complex modelling results to relevant stakeholders, it is essential to tailor information products specifically for them. A strategic approach is to develop web-based decision support tools that seamlessly integrate scientific research, environmental management and industry knowledge. As part of the INTERREG Baltic Blue Growth initiative, an Operational Decision Support System (ODSS) tool has been developed to streamline the dissemination of the latest ecological knowledge on low trophic aquaculture in the Baltic Sea region.

In Task 1.4 of the Baltic MUPPETS project, new process-based modelling was carried out to assess the growth potential of Baltic blue mussels. These models were then linked with regional 3D hydrodynamic models to explore opportunities for expanding mussel farms in the Baltic Sea region while ensuring environmental sustainability. The results were then incorporated into the ODSS portal, enhancing the tool's functionality. This upgrade enables different stakeholders to jointly explore the site-specific potential for mussel farming and its sustainable expansion across the Baltic Sea region.

This Deliverable 1.7 report from the Baltic MUPPETS project focuses on digital maps and details the workflow for their development. It covers the definition of the modelling domain and model type, the development of the model and the production of the maps, providing a comprehensive guide for stakeholders involved in maritime spatial planning and aquaculture development.

2. DATA

2.1 Environmental and geographical data

The activity involved compiling and analysing a wide range of geographical and environmental data, including farm monitoring data and pan-Baltic datasets on key variables from the EU Copernicus and EMODnet infrastructure. The selection of sites for mussel farms depends on several factors such as the availability of designated mussel farming areas (unoccupied by competing activities), water characteristics (salinity, temperature, nutrient levels, quality, phytoplankton density), proximity to land-based infrastructure (reducing travel and transport resources), exposure to environmental elements (ice, wind, waves, currents), and compatibility or synergies with neighbouring activities such as tourism. In addition, potential conflicts with conservation efforts may influence site selection.

2.1.1 Biological datasets

The bivalve distribution data have been compiled from several sources, including national databases from countries around the Baltic Sea, and supplemented by international data repositories such as EurOBIS and EMODnet. This comprehensive dataset, harmonised to include information from hundreds of thousands of stations, covers both hard and soft bottom habitats along the Baltic coast.

Most of the existing experimental measurements of mussel growth in the Baltic Sea have been used to model potential growth and yield across significant environmental gradients in the region. These measurements include original data from INTERREG projects such as Baltic EcoMussel and Baltic Blue Growth, as well as data from various national research initiatives in Estonia, Finland, Sweden, Denmark and Germany. Over ten thousand mussel growth measurements were analysed in this study (for a detailed list of data sources see Kotta et al., 2020 and Kotta et al., 2023).

2.1.2 Physical and biogeochemical datasets

To ensure robust and accurate predictions of ecological processes, it is crucial to carefully select and integrate key environmental variables into model algorithms. Furthermore, the quality of these environmental data must be assessed, as inappropriate selection can compromise the predictive accuracy of the model (MacNally, 2000). Previous research has identified factors such as water salinity, temperature conditions and food availability, as determined by phytoplankton concentration and water flow, as the main drivers of mussel growth in the Baltic Sea region (Kotta et al., 2015). Consequently, the model developed in the Baltic MUPPETS project includes these variables. In addition, carbon sequestration by mussels is influenced by water alkalinity, which is highly correlated with water salinity in the Baltic Sea region. This correlation has allowed us to use salinity as a predictor of carbon sequestration in mussel beds in the region (see the model subsection of this report for more details).

The model calculations for the physical and biogeochemical conditions in the Baltic Sea were derived from the Copernicus open access data portal products (https://data.marine.copernicus.eu/products):

- BALTICSEA_MULTIYEAR_PHY_003_011 (physical parameters)
- BALTICSEA_MULTIYEAR_BGC_003_012 (biogeochemical parameters)

These products provide comprehensive coverage of the entire Baltic Sea, with data at monthly resolution over 56 vertical levels for physical parameters and biogeochemical parameters. Both datasets use a regular horizontal grid with steps of approximately 1 nautical mile in latitude and longitude. The physical data is generated from simulations conducted using the 3D ocean-ice model Nemo (Nucleus for European Modelling of the Ocean), an open community ocean model available at https://nemo-ocean.eu. Within the BAL MFC model system, Nemo version 4.0 is utilized in conjunction with the SI3 sea ice and thermodynamic model. The biogeochemical data is generated using the BAL MFC-ERGOM version of the

ERGOM model, which was originally developed at the IOW, Germany, and later refined at the Danish Meteorological Institute (DMI) and the German Federal Maritime and Hydrographic Agency (BSH). This version of the ERGOM model is run online, coupled with the HBM ocean model code. Our analyses used daily averages of salinity, current velocity, temperature and chlorophyll a concentration.

3. MODEL

3.1 Modelling biomass growth, nutrient and carbon sequestration of the farmed mussels

In the Baltic MUPPETS project a Geographic Information System (GIS) based approach were developed to model site-specific growth of farmed mussels and their nutrient and carbon capture potential along with the sustainable scale-up potential. Such model predictions enable to structure and systematise the site selection process of the new mussel farms and expansion of the existing ones to make sure that environmental sustainability is not compromised.

Dynamic Energy Budget (DEB) modelling, grounded in thermodynamic principles (Sousa et al., 2006) offers a promising method to quantify nutrient emission or sequestration rates at aquaculture sites. DEB theory mechanistically links biology with the abiotic environment by incorporating energy-based trade-offs into fitness measures, which helps predict organisms' physiological responses to environmental factors (Kooijman, 2010). When integrated with hydrodynamic-biogeochemical models, DEB models can realistically estimate the impact of aquaculture on nutrient cycles in coastal areas (Holbach et al., 2020).

Farmed suspension-feeding mussels filter phytoplankton from the water column, incorporating some of the nutrients into their tissues, releasing others back into the sea as inorganic nutrients, and depositing some to the seafloor as faeces (Griffiths et al., 2017; Kotta et al., 2020). These processes can be effectively modelled within the Dynamic Energy Budget (DEB) framework.

In the Baltic MUPPETS project, we combined DEB models of blue mussels (*Mytilus edulis/trossulus*) with a regional hydrodynamic-biogeochemical model to assess the potential of mussel farming in the Baltic Sea (for more details, refer to Kotta et al., 2023). Building on previous models where the DEB model was limited to estimating soft tissue dynamics, with shell metrics previously directly correlated to soft tissue growth, we have adopted a more dynamic approach. By following the DEB rules for product formation as outlined by Kooijman (2010) and Pecquerie et al. (2012) the used method recognises that both energy and carbon allocation to shell production follow the product formation rules of the DEB model and should therefore be associated with the three primary DEB fluxes: assimilation, growth and dissipation.

Co-funded by the European Union

We ran the DEB model across each model grid cell to quantify nutrient and carbon capture capabilities of mussel farming, incorporating the species' responses to ambient salinity, temperature, and food availability. By linking DEB model results to a regional hydrodynamic-biogeochemical modelling framework, we provided a spatially explicit overview of optimal production areas and the scalability of mussel farms in the nutrient-rich and brackish waters of the Baltic Sea.

Our test farm utilizes a smart farming system where mussels are cultivated on nets suspended at depths of 1-5 meters along buoyant lines. Specialized machines clean and harvest the mussels directly from these nets. The farm covers an area of 0.25 hectares and has six 100-metre-long lines, each 50 metres apart. It maintains a stocking density of approximately forty million mussels. There are several reasons for maintaining this distance between the lines. Firstly, this distance reduces the risk of the lines becoming entangled in strong winds and currents. Secondly, research shows that this spacing minimises the likelihood of food limitation, thereby preventing impoverished growth within the farm. In denser configurations, food limitation (phytoplankton) can easily develop. Finally, the spacing makes it easier for harvesters to manoeuvre. (Kraufvelin & Díaz 2015; Kotta et al., 2020). The cultivation period extends from June 1st to October 31st of the following year, allowing for a harvest 1.5 years after the farm's establishment.

The Add-my-Pet procedure (Lika et al., 2011) was used to re-estimate parameters for the Baltic Sea region, enabling simultaneous parameter estimation from empirical data. DEB models for mussels were parameterized using univariate and multivariate datasets, validated against multiple datasets, with most estimates meeting the acceptable margin of error (MRE < 0.2).

The DEB model's assumptions, as detailed by Kooijman (2010), are theoretical and pertain to organism physiology, thus falling outside the primary focus of this work, which applies DEB models. Despite its complexity and the extensive number of parameters, the DEB model remains the most viable option for linking entropy, energy, mass, and nutrient balances, essential for dynamically describing an individual organism. A limitation of the DEB model we employed is its constraints by only temperature, salinity, and food (chlorophyll a). Other environmental factors like oxygen levels and suspended solids can influence mussel physiology. However, we assume these factors do not significantly affect the mussels, based on prior research (Kotta et al., 2015, 2020, 2022). The study area is generally exposed (with no expected hypoxia) and distant from sedimentation zones, with mussel farms positioned high in the water column, minimizing the impact of resuspended solids on feeding and growth. Additionally, there is insufficient data in the literature to consider these environmental factors' metabolic impacts on the organisms.

3.2 Modelling scaling-up potential of mussel farms

The DEB models generated digital maps that visualize the production potential of farmed mussels in the Baltic Sea region, along with their full nutrient and carbon capture capabilities. However, these maps are based on the assumption that nutrients do not limit the growth of mussels on the farm. In scenarios where mussels grow rapidly and water movement is high, mussels may consume more food (phytoplankton or microalgae in the water column) than is

Co-funded by the European Union

replenished from adjacent areas. Under such conditions, the mussels are food-limited, and their growth, along with their nutrient sequestration potential, is lower than the theoretical maximum. In such cases, the farmer must reduce the mussel density on the farm, for example by increasing the distance between the long lines. However, the optimum distance needs to be calculated based on mussel feeding rates and local hydrodynamics. This underscores the importance of incorporating local hydrodynamic conditions into growth models to provide stakeholders with a better understanding of when environmental carrying capacity is exceeded, and mussel growth is reduced. This is particularly relevant when scaling up mussel farms, as larger operations are more likely to experience nutrient depletion, which not only poses an environmental concern but also impacts economic performance due to reduced yields.

To accurately assess the scale-up potential of farming sites while considering the environmental carrying capacity, a specific model was developed that integrates the DEB maps with 3D hydrodynamic modelling. This model evaluates the scalability of mussel farms based on user-defined characteristics in the targeted region, with model predictions being accessible through the ODSS tools.

More specifically, to scale up biomass growth from individual blue mussels to farm scale, realistic densities were applied at the test farms. The chlorophyll a concentration at the farm, influenced by hydrodynamics, was modelled based on the approach in Holbach et al. (2020). This adjusted phytoplankton density was integrated into the DEB model to simulate realistic nutrient discharge and phytoplankton uptake, impacting biomass at harvest. For spatial prediction of nutrient fluxes and growth, the mussel DEB models were independently run for each 1 km² grid cell, assuming no neighbouring mussel farms.

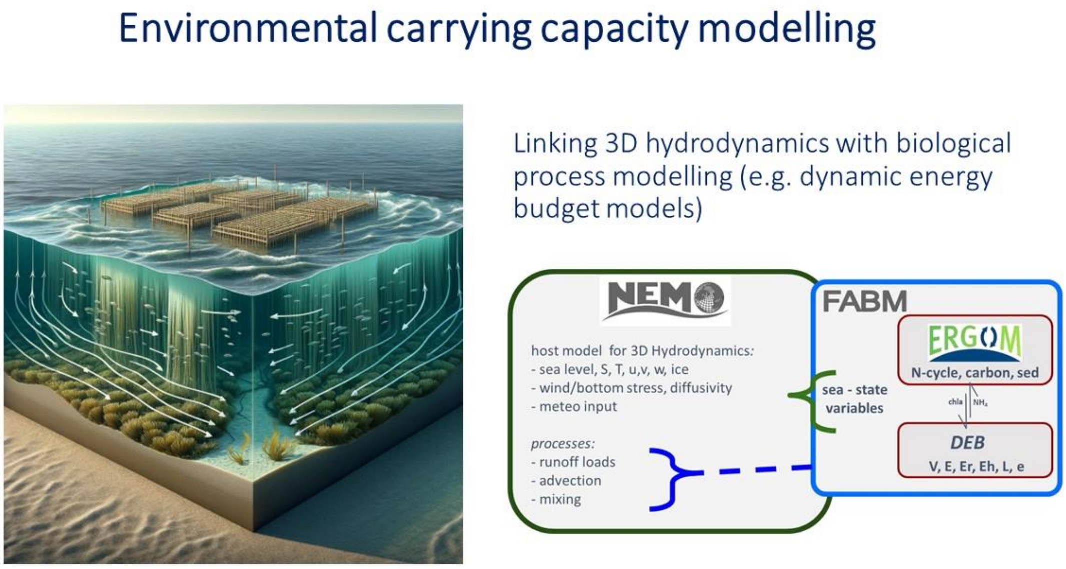

Figure 1. This figure illustrates the theoretical approach of Baltic MUPPETS, which aims to assess the upscaling potential of mussel farming without compromising environmental and economic

sustainability. A dedicated model integrates Dynamic Energy Budget (DEB) maps with 3D hydrodynamic modelling to assess the potential scalability of mussel farms. This model considers user-defined characteristics and local environmental conditions to simulate realistic scenarios of nutrient discharge and phytoplankton uptake, which influence the biomass available at harvest. The results of this model are readily accessible through the Operational Decision Support System (ODSS) tools, enabling effective planning and management.

4. MAPS AND ODSS TOOL

This subsection presents digital maps generated from Dynamic Energy Budget (DEB) models that show key indicators of growth and ecosystem services associated with mussel farming in the Baltic Sea region. These maps show values typical of a standard, relatively small mussel farm, capturing the full potential of farmed mussels under conditions where nutrients do not limit growth. In addition, the Operational Decision Support System (ODSS) scale-up tool uses these maps and links them to 3D hydrodynamic models to predict realistic growth yields for larger farms.

The interactions between biota and environmental gradients are complex and involve many abiotic and biotic factors. The overall results describe the spatial patterns and locations of productive areas for blue mussel farms in the Baltic Sea region. Direct environmental gradients, particularly salinity, play a crucial role in determining the distribution of mussels in the region. Predictions show that the yield of mussel biomass increases non-linearly with increasing salinity. In regions where salinity is as low as 3 practical salinity units (psu), mussels are working close to the limits of their salinity tolerance. Below this level, mussel growth and reproduction are not viable, mainly due to the high cost of osmoregulation. The model also shows that once salinity exceeds this threshold, the production potential of mussels increases sharply and then stabilises at salinities above 6 psu.

Within their optimal range, however, resource gradients play an important role in influencing their production potential. Food availability is essential for sedentary benthic suspension feeders and the main environmental indicators of food availability for mussels are wave exposure and phytoplankton biomass (water chlorophyll a content of water). Mussels can rapidly deplete food resources in the near-bottom water layer, leading to starvation even in the presence of abundant phytoplankton if water movement is insufficient. However, in the upper water column where mussels are cultivated, better water exchange and higher concentrations of phytoplankton make food limitation less likely. Thus, it is salinity rather than other environmental factors that dominates in shellfish production yields in the Baltic Sea region.

The DEB model and the ODSS scale-up tool predicted area-specific production yields for a standard farm of 0.25 hectares (Figure 2). The highest production yield, approximately 650 tonnes of wet weight, was found in the highly saline areas of the outer Baltic Sea. In the Kattegat and Danish Straits, the production yield exceeded 128 tonnes of wet weight. However, as salinity decreased, the predicted production yield also diminished. In most of the Southern Baltic Proper, production yields varied between 28 and 128 tonnes of wet weight.

Co-funded by the European Union

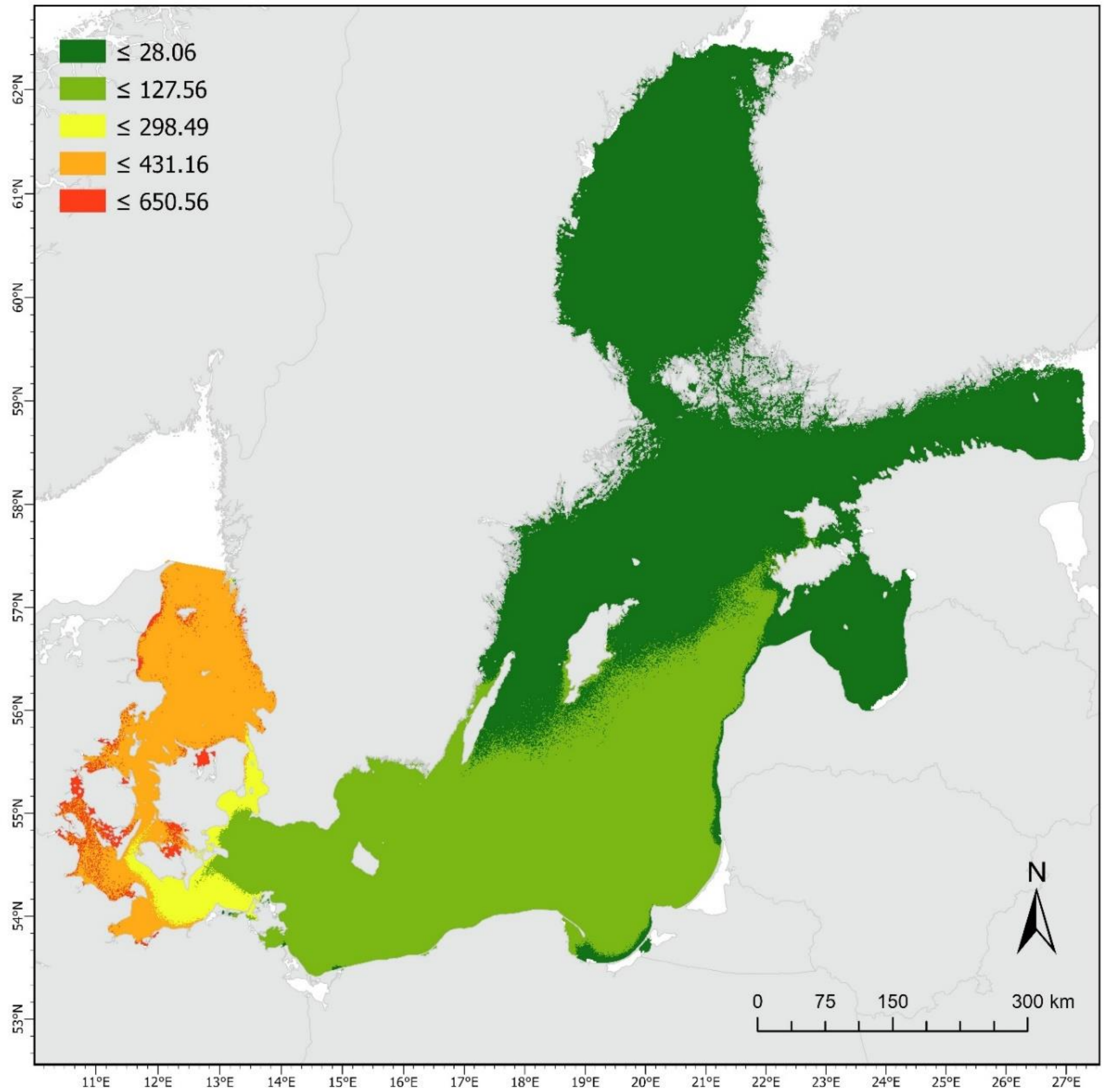

Figure 2. Area-specific mussel production yields of a standard 0.25 ha farm in tonnes wet weight in the Baltic Sea region.

The potential for nutrient and carbon capture, defined by the species' responses to ambient salinity, temperature, and food availability, largely mirrored the spatial patterns of mussel production yields. Overall, the assessment of nutrient and carbon capture in the harvest biomass aligns with salinity gradients in the Baltic Sea (Figure 3). In high-salinity areas such as the outer Baltic Sea (including the Kattegat and Danish Straits), nitrogen (N) capture reaches its peak values of 50 to 120 kilograms (kg) and phosphorus (P) capture ranges from 6 to 14 kg in a standard 0.25-hectare farm. Carbon capture in mussel shells also peaks there, ranging from 40,000 to 90,000 kg of carbon. As salinity sharply decreases toward the Baltic Proper and its central region, the capture of nutrients and carbon decreases rapidly to 13 to 50 kg of N, 1.3 to 6 kg of P, and 10,000 to 40,000 kg of C. This decline continues more gradually throughout the Baltic Proper. The lowest nutrient and carbon capture, with less than 13 kg of

N, less than 1.3 kg of P, and 1,000 to 10,000 kg of C, occurs in the innermost regions (the Gulf of Finland, the Gulf of Bothnia, and the Gulf of Riga), where mussels are at the lower limit of their salinity tolerance.

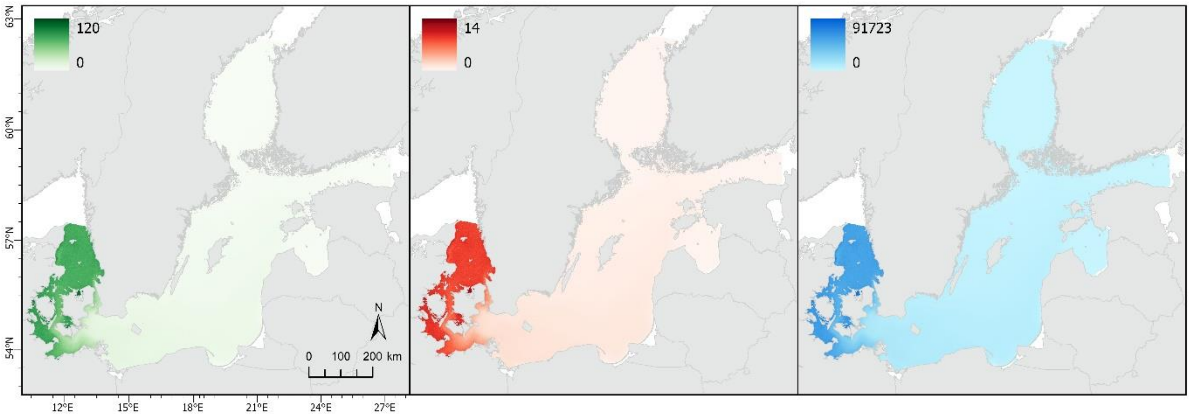

Figure 3. Total incorporated nitrogen (left), phosphorus (centre), and carbon (right) in kilograms harvested from a standard 0.25-hectare blue mussel farm in the Baltic Sea region.

Similar to nutrient and carbon capture in mussel biomass, the nutrient and carbon filtration capacity during a harvest cycle of a 0.25-hectare mussel farm is highest in areas of high salinity, such as the outer Baltic Sea, including Kattegat and the Danish Straits (Figure 4). In these high-salinity areas, nitrogen filtration ranges from 6,000 to 20,000 kilograms (kg), phosphorus filtration ranges from 700 to 2,300 kg, and carbon filtration ranges from 35,000 to 116,000 kg per harvest cycle.

The filtration capacity decreases rapidly as salinity decreases toward the Baltic Proper. In the western part of the Southern Baltic Proper, nitrogen filtration ranges from 2,300 to 6,000 kg, phosphorus filtration from 270 to 700 kg, and carbon filtration from 13,000 to 35,000 kg. In most of the Baltic Proper, nitrogen filtration ranges from 390 to 2,300 kg, phosphorus filtration from 45 to 270 kg, and carbon filtration from 2,200 to 13,000 kg.

The lowest nutrient and carbon filtration rates occur in the innermost regions of the Baltic Sea, including the Gulf of Finland, Gulf of Bothnia, and Gulf of Riga. In these areas, where mussels are at the lower limit of their salinity tolerance, nitrogen filtration is less than 390 kg, phosphorus filtration is less than 45 kg, and carbon filtration is less than 2,200 kg.

Co-funded by
the European Union

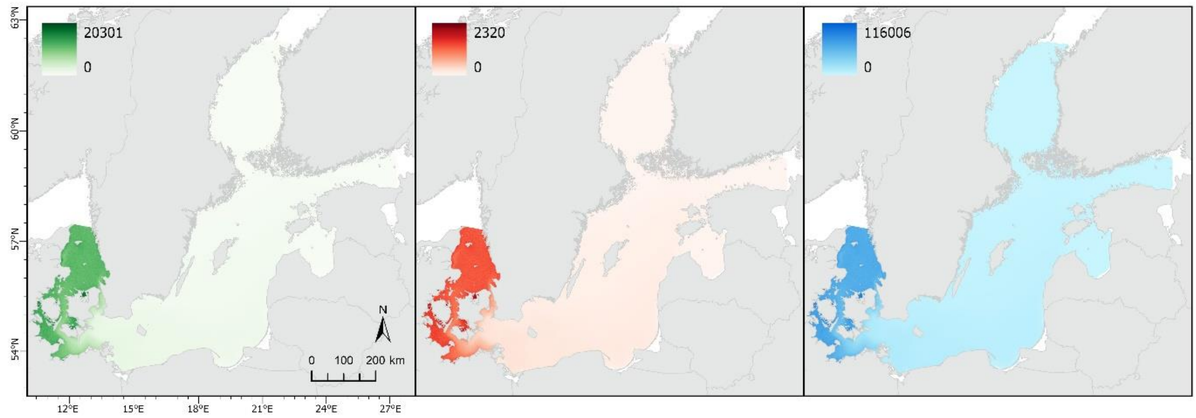

Figure 4. Filtration capacity of nitrogen (left), phosphorus (centre), and carbon (right) in kilograms during a harvest cycle in a standard 0.25-hectare mussel farm.

The Operational Decision Support System (ODSS) tool is a comprehensive resource designed to facilitate the planning and management of mussel farms in the Baltic Sea region. It offers a user-friendly interface that displays multiple map layers, including environmental conditions, human uses, production potential, and the capacity for nutrient and carbon capture.

The "Plan Your Farm" feature within ODSS allows users to select a specific area of interest and provides detailed statistics across various dimensions—environmental factors, human activity, potential farm yields, and ecosystem services such as nutrient and carbon capture. This functionality is crucial for identifying locations that maximize synergies and minimize conflicts, enabling the quick identification of optimal cultivation sites that also enhance ecosystem service delivery.

In order to assist in the assessment of the scale-up potential of mussel farming sites, taking into account the carrying capacity of the environment, a specific tool has been developed within the ODSS portal. This tool integrates DEB maps with 3D hydrodynamic modelling. Users first define their area of interest within the Baltic Sea region and enter farm parameters, such as the density of mussel growth substrates per surface area and their expected yield relative to the theoretical maximum. In some cases, it may be more advantageous to opt for denser mussel growth substrates, even if this results in slightly lower growth yields - for example, a farmer might accept 90% of the maximum growth potential. If no compromise is desired, farmers can set the growth yield parameter to 100%. Once the parameters have been selected, the tool assesses the potential for food limitation for the mussel farm in the specified region and recommends an appropriate configuration in terms of substrate density per area.

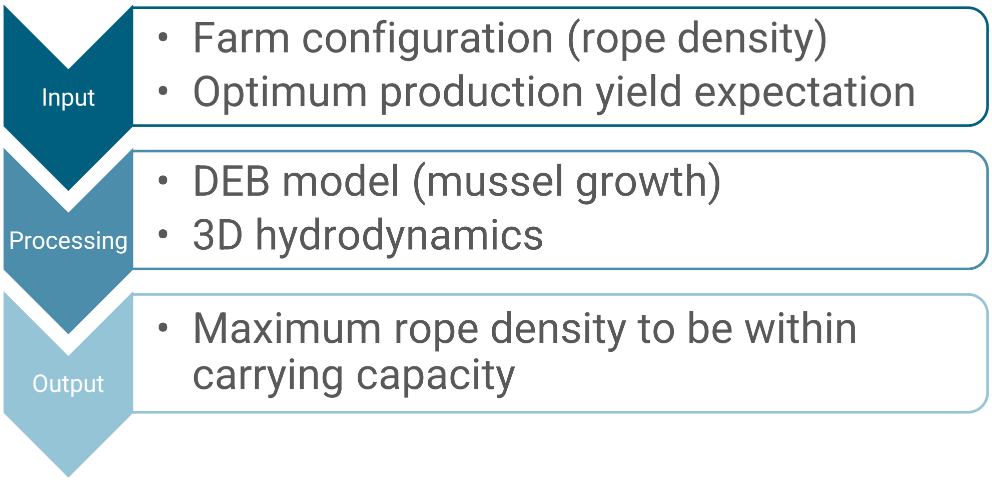

Figure 5. The Baltic MUPPETS tool facilitates information flow, detailing user-specific parameters, dynamic analysis, and outcomes. For a graphical representation of the tool's interface, please refer to the figure below.

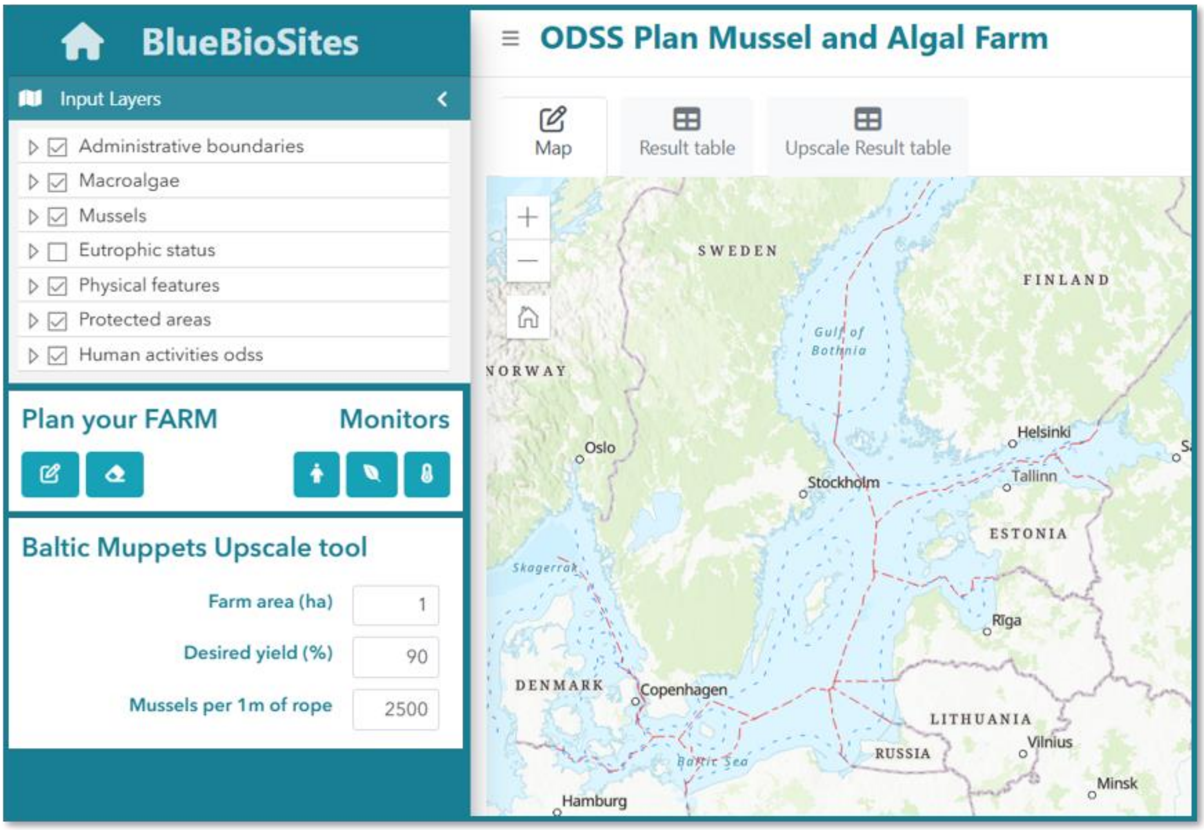

Figure 6. Graphical interface of the ODSS "Plan Your Farm" tool with Baltic MUPPETS functionality.

The Plan Your Farm tool allows users to select a site within the Baltic Sea region and access detailed information about the site, including typical ranges of key hydrophysical, chemical, and biological variables, the intensity of various human activities, and the full potential for mussel farming with nutrient and carbon capture capabilities. This information enables the identification of synergies with existing human uses and helps avoid potential conflicts. Moreover, certain environmental parameters, such as ice and wave conditions, can be directly utilized in farm planning processes. Other parameters, such as farm yield, can be used to predict economic outcomes. Additionally, the tool facilitates the assessment of mussel farm scaling-up potential without compromising environmental sustainability.

CONCLUSIONS

In the current task, a Dynamic Energy Budget (DEB) model has been developed to produce digital maps visualising the production potential of farmed mussels in the Baltic Sea region, together with their nutrient and carbon sequestration capacity. By integrating the DEB model with 3D hydrodynamic modelling, a digital tool has been developed to assess the site-specific scale-up potential of farming sites, taking into account the carrying capacity of the environment. This model assesses the scalability of mussel farms based on user-defined characteristics in the target region. Accessible through the ODSS tools, these maps and tools serve multiple stakeholders. Governments can use them for maritime spatial planning to identify optimal areas for mussel growth, eutrophication mitigation and restoration potential, ensuring that environmental carrying capacity is not exceeded while maximising restoration benefits. Industry partners can select the best farming areas according to their value chains and product development needs, avoiding conflicts and exploiting synergies by taking into account other human activities and environmental conditions. The tool also supports the effectiveness of mussel farms associated with the Baltic Muppets project, such as Wittrup Seafood, Ecopelag and Kieler Meeresfarm. In addition, academia can use this tool to educate students and the general public about low trophic aquaculture and its potential for environmental restoration.

Co-funded by the European Union

REFERENCES

Buer, A.L., Maar, M., Nepf, M., Ritzenhofen, L., Dahlke, S., Friedland, R., Krost, P., Peine, F. & Schernewski, G. (2020). Potential and feasibility of *Mytilus* spp. farming along a salinity gradient. *Frontiers in Marine Science*, **7**, 371. https://doi.org/10.3389/fmars.2020.00371

Bertilius, K. & Vidakovic, A. (2019). Food and feed safety aspects of mussel-and insect-based feed. Report of the INTERREG BSR Baltic Blue Growth project.

Carlsson, M.S., Engström, P., Lindahl, O., Ljungqvist, L., Petersen, J.K., Svanberg, L. & Holmer, M. (2012). Effects of mussel farms on the benthic nitrogen cycle on the Swedish west coast. *Aquaculture Environment Interactions*, **2**, 177–191. https://doi.org/10.3354/aei00039

EC. (2012). European Commission, Blue Growth opportunities for marine and maritime sustainable growth COM/2012/0494 final

FAO. (2022). The State of World Fisheries and Aquaculture 2022. Towards Blue Transformation. Rome, FAO. https://doi.org/10.4060/cc0461en

Gren, M., Lindahl, O. & Lindqvist, M. (2009). Values of mussel farming for combating eutrophication: an application to the Baltic Sea. *Ecological Engineering*, **35,** 935–945. https://doi.org/10.1016/j.ecoleng.2008.12.033

Griffiths, J.R., Kadin, M., Nascimento, F.J.A., Tamelander, T., Törnroos, A., Bonaglia, S., Bonsdorff, E., Brüchert, V., Gårdmark, A., Järnström, M., Kotta, J., Lindegren, M., Nordström, M.C., Norkko, A., Olsson, J., Weigel, B., Žydelis, R., Blenckner, T., Niiranen, S. & Winder, M. (2017). The importance of benthic-pelagic coupling for marine ecosystem functioning in a changing world. *Global Change Biology*, **23**, 2179–2196. https://doi.org/10.1111/gcb.13642

Holbach, A., Maar, M., Timmermann, K. & Taylor, D. (2020). A spatial model for nutrient mitigation potential of blue mussel farms in the western Baltic Sea. *Science of The Total Environment*, 736, 139624. https://doi.org/10.1016/j.scitotenv.2020.139624

Hu, S., Wang, Y. & Han, H. (2011). Utilization of waste freshwater mussel shell as an economic catalyst for biodiesel production. *Biomass Bioenergy*, **35,** 3627–3635. https://doi.org/10.1016/j.biombioe.2011.05.009

Kijewski, T., Zbawicka, M., Strand, J., Kautsky, H., Kotta, J., Rätsep, M. & Wenne, R. (2019). Random forest assessment of correlation between environmental factors and genetic differentiation of marine populations: a case of the mussels *Mytilus*. *Oceanologia*, **61**, 131–142. https://doi.org/10.1016/j.oceano.2018.08.002

Kooijman, S.A.L.M. (2010). Dynamic Energy Budget Theory for Metabolic Organisation (3rd ed.). Cambridge University Press. https://doi.org/10.1017/CBO9780511805400

Kotta, J., Futter, M., Kaasik, A., Liversage, K., Rätsep, M., Barboza, F.R., Bergström, L., Bergström, P., Bobsien, I., Díaz, E., Herkül, K., Jonsson, P.R., Korpinen, S., Kraufvelin, P., Krost, P., Lindahl, O., Lindegarth, M., Lyngsgaard, M.M., Mühl, M., Sandman, A.N., Orav-Kotta, H., Orlova, M., Skov, H., Rissanen, J., Šiaulys, A., Vidakovic, A. & Virtanen, E. (2020).

Cleaning up seas using blue growth initiatives: mussel farming for eutrophication control in the Baltic Sea. *Science of The Total Environment*, **709**, 136144. https://doi.org/10.1016/j.scitotenv.2019.136144

Kotta, J., Oganjan, K., Lauringson, V., Pärnoja, M., Kaasik, A., Rohtla, L., Kotta, I. & Orav-Kotta, H. (2015). Establishing functional relationships between abiotic environment, macrophyte coverage, resource gradients and the distribution of *Mytilus trossulus* in a brackish non-tidal environment. *PLoS ONE*, **10**, e0136949. https://doi.org/10.1016/j.scitotenv.2019.136144

Kotta, J., Raudsepp, U., Szava-Kovats, R., Aps, R., Armoskaite, A., Barda, I., Bergström, P., Futter, M., Gröndahl, F., Hargrave, M., Jakubowska, M., Jänes, H., Kaasik, A., Kraufvelin, P., Kovaltchouk, N., Krost, P., Kulikowski, T., Kõivupuu, A., Kotta, I., Lees, L., Loite, S., Maljutenko, I., Nylund, G., Paalme, T., Pavia, H., Purina, I., Rahikainen, M., Sandow, V., Visch, W., Yang, B. & Barboza, F.R. (2022). Assessing the potential for sea-based macroalgae cultivation and its application for nutrient removal in the Baltic Sea. *Science of The Total Environment*, **839**, 156230. https://doi.org/10.1016/j.scitotenv.2022.156230

Kotta, J., Stechele, B., Barboza, F.R., Kaasik, A. & Lavaud, R. (2023). Towards environmentally friendly finfish farming: A potential for mussel farms to compensate fish farm effluents. *Journal of Applied Ecology*, **60**, 1314–1326.

Kraufvelin, P. & Díaz, E.R. (2015). Sediment macrofauna communities at a small mussel farm in the northern Baltic proper. *Boreal Environment Research,* **20**, 378–390.

Lika, K., Kearney, M.R. & Kooijman, S.A.L.M. (2011). The "covariation method" for estimating the parameters of the standard Dynamic Energy Budget model II: Properties and preliminary patterns. *Journal of Sea Research*, **66**, 278–288. https://doi.org/10.1016/j.seares.2011.09.004

Maar, M., Saurel, C., Landes, A., Dolmer, P. & Petersen, J.K. (2015). Growth potential of blue mussels (*M. edulis*) exposed to different salinities evaluated by a Dynamic Energy Budget model. *Journal of Marine Systems,* **148**, 48–55. https://doi.org/10.1016/j.jmarsys.2015.02.003

MacNally, R. (2000). Regression and model-building in conservation biology, biogeography and ecology: the distinction between – and reconciliation of – 'predictive' and 'explanatory' models. *Biodiversity and Conservervation*, **9**, 655–671.

McLaughlan, C., Rose, P. & Aldridge, D.C. (2014). Making the best of a pest: The potential for using invasive zebra mussel (*Dreissena polymorpha*) biomass as a supplement to commercial chicken feed. *Environmental Management,* **54**, 1102–1109. https://doi.org/10.1007/s00267-014-0335-6

Nkemka, V.N. & Murto, M. (2013). Two-stage anaerobic dry digestion of blue mussel and reed. *Renewable Energy*. **50,** 359–364. https://doi.org/10.1016/j.renene.2012.06.041

OECD/FAO. (2021). OECD-FAO Agricultural Outlook 2021-2030, OECD Publishing, Paris, https://doi.org/10.1787/19428846-en

Pecquerie, L., Fablet, R., De Pontual, H., Bonhommeau, S., Alunno-Bruscia, M., Petitgas, P. & Kooijman, S.A.L.M. (2012). Reconstructing individual food and growth histories from biogenic carbonates. *Marine Ecology Progress Series*, **447**, 151–164. https://doi.org/10.3354/meps09492

Rydin, E., Kumblad, L., Wulff, F. & Larsson, P. (2017) Remediation of a eutrophic bay in the Baltic Sea. *Environmental Science & Technology,* **51**, 4559–4566. https://doi.org/10.1021/acs.est.6b06187

Sousa, T., Mota, R., Domingos, T. & Kooijman, S.A.L.M. (2006). Thermodynamics of organisms in the context of dynamic energy budget theory. *Physical Review E*, **74**, 051951. https://doi.org/10.1103/PhysRevE.74.051901

Stigebrandt, A., Liljebladh, B., de Brabandere, L., Forth, M., Granmo, Å., Hall, P., Hammar, J., Hansson, D., Kononets, M., Magnusson, M., Norén, F., Rahm, L., Treusch, A.H. & Viktorsson, L. (2015). An experiment with forced oxygenation of the deepwater of the anoxic by fjord, Western Sweden. *AMBIO*, **44**, 42–54. https://doi.org/10.1007/s13280-014-0524-9

Stuckas, H., Stoof, K., Quesada, H. & Tiedemann, R. (2009). Evolutionary implications of discordant clines across the Baltic *Mytilus* hybrid zone (*Mytilus edulis*, *Mytilus trossulus*). *Heredity*, **103**, 146–156. https://doi.org/10.1038/hdy.2009.37

Vidakovic, A., Langeland, M., Sundh, H., Sundell, K., Olstorpe, M., Vielma, J., Kiessling, A. & Lundh, T. (2016), Evaluation of growth performance and intestinal barrier function in Arctic Charr (*Salvelinus alpinus*) fed yeast (*Saccharomyces cerevisiae*), fungi (*Rhizopus oryzae*) and blue mussel (*Mytilus edulis*). *Aquaculture Nutrition*, **22**, 1348–1360. https://doi.org/10.1111/anu.12344

Co-funded by the European Union