Site-Selection in Baltic Sea mussel farming:

Current practices and future outlook

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BONUS OPTIMUS Report

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hjarnøhavbrug ...fish farming since 1952

OPTIMUS: Optimization of mussel mitigation culture for fish feed in the Baltic Sea
Front page image: Blue mussel farm in As Vig, Horsens Denmark, photo: Per Bergström

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Executive summary

The present report studies site–selection for mussel farming in the Baltic Sea and its place in the marine spatial planning process. Providing a comprehensive overview of the complexity of site-selection for Mussel farming in the Baltic Sea. Aquaculture, including mussel farming is one of the fastest growing food-producing sectors worldwide. This expansion of marine bivalve cultivation and an increased global environmental awareness have encouraged a more ecosystem-based perspective for managing and developing shellfish farming in the south-west Baltic Sea.

The suitability of a site for a specific activity, such as mussel farming, is dependent on the point of view. Here, we use the carrying capacity concept toward sustainable mussel farming in the Baltic Sea giving an overview of tools for site-selection and marine spatial planning in the Baltic Sea region and a global outlook on similar tools. Furthermore, we also give a brief overview of granting of permissions of mussel farming in the south-west Baltic Sea region on an European and national level.

1. Background

1.1 About Optimus

The OPTIMUS project is a three year project financed through the BONUS program (Art 185), funded jointly by the EU, the Innovation Fund Denmark, the German Ministry for Education and Science (BMBF), the Swedish Agency for Marine and Water Management and the National Centre for Research and Development, Poland; which aims to provide robust evidence based documentation (ecological, social, and economic) on optimized use of farmed mussels as a mitigation tool for eutrophication that in turn can be a sustainable protein-rich feed stuff for fish. The project has partners from Denmark, Germany, Poland and Sweden and runs from 2017-2020 and will provide documentation that can contribute to solutions in order for mussel farming to become an important activity in the Baltic Sea.

1.2 Aim of report

Aquaculture of shellfish is an example of blue growth potential that will not add pressure to the Baltic ecosystem. Instead it has the potential to mitigate some of the effects of excess nutrients loads and is tested as a tool for mitigating eutrophication in coastal environments. The basic mechanism behind this is that when filter-feeding mussels filtrate the water, they take up nutrients that have been incorporated into microalgae; nutrients which are removed from the system when the mussels are harvested. Furthermore, the filtration also contributes to increased water transparency. However, as with many other marine economic activities, it should be a subject of marine spatial planning for designation of suitable sites. The present report studies site–selection for mussel farming in the Baltic Sea and its place in the marine spatial planning process.

1.3 Mussel farming in the Baltic

Cultivation of mussels for human consumption holds a great potential for producing food and feed from the sea. Farming of mussels is historically not very well developed in the Baltic Sea. Mainly during the last decade, mussel farming practices have developed in the area, most often originating in research projects. As an example, German trials on shellfish farming have been conducted in the Baltic Sea since the 19th century, but is was first in 2010 that the first successful commercial farm was established in the Kiel Fjord (originating in the EBAMA research project). Low salinity and harsh weather conditions with ice cover during winter season, together with low regional and local interest in mussel products have prevented development in the area.

As environmental quality goals in the Baltic Sea have not been met, and in line with the EU Baltic Sea Region Strategy for Blue Growth pointing to mussel farming as a promising opportunity for sustainable aquaculture in the Baltic Sea region, the ecosystem services provided by mussel farming have come into focus. Harvest of mussels is a relatively new method for reducing phosphorous and nitrogen loads in the Baltic Sea, and its effectiveness is highly debated due to the sub-optimal growth conditions (low salinity). However, blue mussel farming as a business in the Baltic Sea is still in the early days and further investigation is required to fully evaluate the potential for both production for human consumption, and as a mitigation measure.

1.4 Marine Spatial Planning in the Baltic Sea

To realise the potential of mussel farming in the Baltic Sea region, the ecosystem services must be documented, and efficient farming practices have to be developed for harsh environmental conditions in the area. It is, equally important that its development are done in concurrence with all other interests in the region. Thus, tools taking these different interests into account are needed; tools that can help both farmers and managers to identify optimal sites where economically sustainable mussel farming can be integrated in the area with local acceptance (Falconer et al. 2019). After initial hesitation in several countries, aquaculture stakeholders and fisheries are becoming more and more actively engaged in spatial planning to secure the availability of the most suitable sites for their activities (Jentoft and Knol 2014). The Maritime Spatial Planning (MSP) Directive (European Commission 2014) stipulates that maritime spatial plans should be based on reliable data and encourages member states to share information and make use of existing instruments and tools for data collection. Given the spatial context of MSP, applications to scale economic, environmental and social dimensions geographically are highly demanded (Kapetsky et al. 2013). Identifying suitable sites for aquaculture activity is even more challenging as use does not only depend on physical, chemical and biological factors, but also on political, economic and social criteria (Wever et al. 2015).

2. Site selection for sustainable mussel farming

2.1 Carrying capacities – a multidisciplinary view on site selection

Aquaculture, including mussel farming is one of the fastest growing food-producing sectors worldwide. This expansion of marine bivalve cultivation and an increased global environmental awareness have encouraged a more ecosystem-based perspective for managing and developing shellfish farming. An important part of this management is to estimate the capacity (carrying capacity) of an area to support the cultured species. However, defining and evaluating this carrying capacity is less straight-forward. Historically, the localisation of aquaculture activities has been based on a combination of local demand and accessibility in physical and legislative terms. Since bivalve farming competes with other activities for space and resources, its development can have negative impacts on these other activities, for example, industry or environmental goods and services. Thus, it is important that the carrying capacity of these systems is considered in development and site-selection processes for bivalve farming in the Baltic Sea. Carrying capacity is not limited to farm or population size issues, but also helps set the upper limits for aquaculture production given the environmental limits and social acceptability, avoiding unacceptable change to both the natural ecosystem and the social functions and structures of the area. Hence the system's carrying capacity can be described as four functional groups (McKindsey et al. 2006); "Physical carrying capacity", "Production carrying capacity", "Ecological carrying capacity" and "Social carrying capacity" (Figure 1).

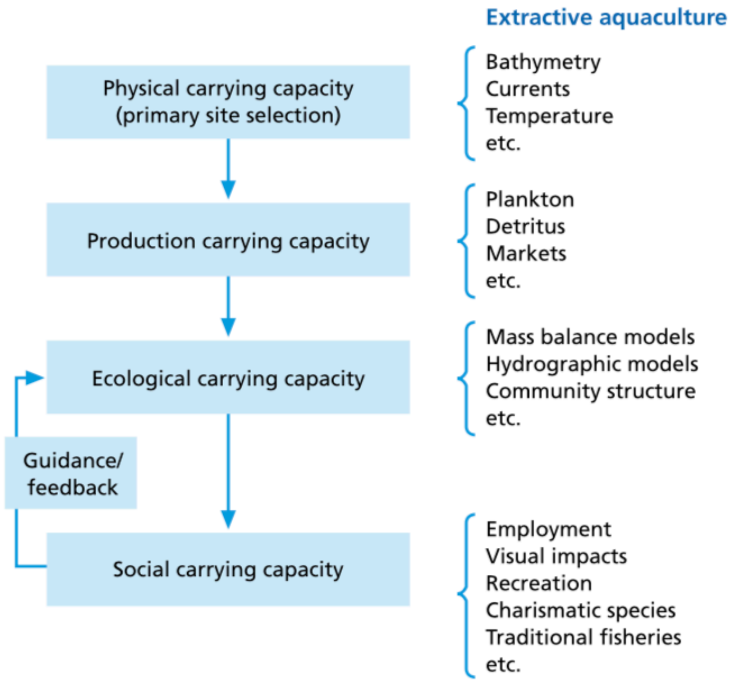

Figure 1. Hierarchical structure to determine carrying capacity of a given area. Social carrying capacity feeds back directly to ecological carrying capacity to provide guidance to choose pertinent response variables to measure. Modified from McKindsey et al (2006) and (Ross et al. 2013)

Physical carrying capacity is the suitability of an area for development and production of a given aquaculture activity by taking physical and chemical factors of the environment into account, and describing the geographically available area. This is useful for quantifying the area potentially available for mussel farming in the ecosystem. However, the physical carrying capacity does not take regulation into account and provides little information for management.

Production carrying capacity estimates the optimal production (maximum level) that provides the maximum economic return, and is normally considered at the scale of individual farm. In mussel farming, this carrying capacity takes farming technology, production systems, and the investment required into account.

Ecological carrying capacity is roughly defined as the magnitude of aquaculture production that can be supported by the ecosystem without having significant unacceptable changes to the ecological environment (processes, species, populations, communities etc.). The degree of unacceptable changes is highly dependent on social values and consequently varies among social communities. In contrast to production carrying capacity, ecological carrying capacity considers the whole ecosystem and all activities involved in the aquaculture process (McKindsey et al. 2006). Predicting the ecological carrying capacity is vital for the assessment of impacts of large-scale mussel farming and identifying appropriate indicators and metrics to follow up the performance.

Social carrying capacity is the most complex of the four carrying capacity types to determine; it is the amount of aquaculture activity that can take place in a specific area without adverse social impacts. Not only does it require information on the three other types, but is also a trade-off between stakeholders to meet the demands of the population (e.g. traditional fisheries, employment in other sectors etc.) as well as the environment (habitat protection etc.). Determining social carrying capacity requires the involvement of many stakeholders and requires communication between scientists and stakeholders to obtain the expected outcome of sustainable management of resources and equity of all stakeholders.

Production carrying capacity has mainly been the operational definition of "carrying capacity". However, the process of estimating carrying capacity has been rapidly evolving over the last decade, from a focus on maximizing production, to a more ecosystem based management (EBM) approach. In an EBM approach, estimating aquaculture potential (=physical carrying capacity) is the first step toward planning for aquaculture development.

The suitability of a site for a specific activity, such as mussel farming, is dependent on the point of view. Aquaculture stakeholders, decision- and policy makers, the social community, and other competing interests often have different views and assign different aspects into focus in determining if a site is suitable or not. Combining all of these views can be challenging and site suitability analysis (i.e. determining the four carrying capacities) is a key issue in contemporary marine spatial planning, including planning of mussel farming facilities. Some examples of factors considered within the four carrying capacity groups are listed in Table 1.

Table 1. Examples of factors included when estimating the four categories of carrying capacity for aquaculture activities

Carrying capacity category	Factors
Physical	
	Water availability
	Accessibility
	Water quality
	Food availability
	Hydrodynamics
Production	
	Production intensity
	Production yield
	Market value
Ecological	
	Waste dispersal
	Habitat deterioration
	Biodiversity
	Nutrient and organic matter
	Eutrophication
	Oxygen levels
Social	
	Competition for space
	Employment
	Acceptability
	Value to community
	Regulation and legislation

Careful site selection is essential in order to achieve sustainable mussel farming and minimizing potential environmental impacts. Experience with and knowledge of mussel farming are important as many aspects and factors are influencing the sustainability of the farm.

2.2 Factors limiting the physical carrying capacity

From the farmer's perspective, the crucial factor in selecting a site is finding one that can sustain an economically viable farm. This in turn requires favourable and stable production, which in turn requires environmental conditions suitable for mussel growth. Being a marine species, blue mussels prefer saline waters (>4 PSU but preferably higher) and the water current should not be too strong. For practical reasons (anchoring etc.) the water should not be too deep (e.g. <30m) and areas with frequent drift ice winters should be avoided. There should also be occurrence sufficient supply of mussel larvae during the settling period, and enough food available in the water. Furthermore, areas with a large number of predators, such as Eider ducks, are less suitable due to the potential risk of losing mussels.

2.3 Factors limiting the production carrying capacity

From an economical perspective, it is also preferable to have a site at a reasonably close distance to harbours, since transport is expensive for the farmer both when establishing and maintaining the farm and during harvest. The mussels need enough food in the form of phytoplankton to grow reasonably and the food transport into the farm needs to be sufficient to prevent serious within-farm food limitation. Therefore, a certain critical horizontal water flow is necessary. This critical flow, however, depends on the density of mussels within a farm, as well as on their actual filtration activity. The first depends on the farm setup, respectively the density of spat collector material, while the latter depends on environmental conditions, mostly temperature and phytoplankton concentration.

2.4 Factors limiting the ecological carrying capacity

Even though environmental conditions are favourable for mussel growth, the concomitant environmental impact of the farm may be unacceptable. Aquaculture needs to share the aquatic space with other marine environmental interests, both in terms of space requirements and by its interaction with the environment. Some uses can co-occur, while others may be completely counteractive. The interaction between mussel farming and protection of the environment can be both positive and negative. A negative impact are largely attributed to increased sedimentation of organic matter due to mussel faecal pellets settling on the seabed. This material undergoes mineralization, depleting oxygen in the bottom water, which leads to degradation of living organisms' assemblages in the bottom affected by the farm. However, the knowledge about the impacts of mussel farming on the ecosystem in the Baltic is limited, and most conclusions are drawn using knowledge on mussel farming impacts in other parts of Northern Europe. It is important that the mussel farming does not counteract conservation interests or has negative impacts on the pelagic or benthic environment, thus a good bottom water exchange is needed in order to avoid low oxygen benthic conditions and strong accumulation of faecal pellets directly under a farm.

The Eider duck can also contribute to increased biodeposits on the bottom by dislodging mussels from the farm, potentially enhancing unacceptable environmental impacts.

2.5 Factors limiting the social carrying capacity

A good site for the farmer is not always optimal from other perspectives. There could be regulatory constraints on local, regional or national levels limiting or preventing farming practices at certain sites. With limited space, every activity can potentially cause conflicts with other uses and activities. Some areas are prohibited for farming practices due to conflicting interests, such as navigable waterways, while with other interests, such as recreation activities, requires a trade-off between the interests in the need for space. Some of the most important competing interactions with mussel farming are with transport, fishery, energy production, tourisms and recreational activities, such as boating/sailing. However, there are also a range of beneficial interactions between mussel farming practise and other interests. Examples include increased local food production, increased knowledge of ecosystem services provided by mussel farms in combination with increased education of the human foot print on the ocean, and increased local interest and acceptance for benefits of aquaculture with increased local tourism. Other important aspects of mussel farming are related to the creation of job opportunities and local economic impact.

2.6 Nutrient mitigation: implications for carrying capacities

Eutrophication is considered as one of the main ecological threats to the Baltic Sea. Over the past century, a large surplus of nutrients has been built up in the area affecting the aquatic ecosystem, as well as our prospects to enjoy the sea. In order to realize a recovery of the Baltic Sea, and to meet the goals set by the EU Water Framework Directive, the Marine Strategy Framework Directive and the goals of the HELCOM Baltic Sea Action Plan, future nutrient abatement efforts are needed. The positive the interactions between mussel farming and the environment are related to filter-feeding by mussels, which reduces suspended organic matter in the sea, increasing water transparency and Secchi depth and generally improving overall water quality. Consequently, farming of blue mussels has been suggested as a potential mitigation measure in the Baltic Sea to remove nitrogen and phosphorous (e.g. Lindahl et al. 2005, Petersen et al. 2014). The mussels incorporate nutrients into their tissues and harvesting farmed blue mussels removes nutrients from the sea, and returns them to land.

3. Site selection in practice

3.1 Granting of permissions

3.1.1 European regulations

On a more global scale, the UN Convention on the Law of the Sea (LOSC) contains some articles relevant for shellfish farming, especially Art 208 which states that countries should enforce laws and regulations and other measures to prevent, reduce and control pollution of the marine environment. Restrictions in granting of permission can occur at many levels including European and national levels. Within the European Union there are several regulations that can affect aquaculture practices. Some of the most important regulations concerning marine shellfish farming in Europe are listed in Table 2.

Table 2. Important regulations and legislative frameworks for Shellfish farming at European level.

Legislation/Regulation	No	Year
Commission Regulation (EU) No 768/2013 of 16 August 2013 amending Annex III to Regulation (EC) No 853/2004 of the European Parliament and of the Council as regards permitted limits of yessotoxins in live bivalve molluscs	786/2013	2013
Commission Regulation (EU) No 15/2002 of 10 January 2011 amending Regulation (EC) No 2074/2005 as regards recognised testing methods for detecting marine biotoxins in live bivalve molluscs	15/2011	2011
Commission Regulation (EC) No 333/2007 of 27 March 2007 laying down the methods of sampling and analysis for the official control of the levels of lead, cadmium, mercury, inorganic tin, 3-MCPD and benzo(a)pyrene in foodstuffs	333/2007	2007
Commission Regulation (EC) No 1881/2006 of 19 December 2006 setting maximum levels for certain contaminants in foodstuffs	1881/2006	2006
Commission Regulation (EC) No 1664 amending Regulation (EC) No 2074/2005 as regards implementing measures for certain products of animal origin intended for human consumption and repealing certain implementing measures	1664/2006	2006
Commission Regulation (EC) No 2074 laying down implementing measures for certain products under Regulation (EC) No 853/2004 of the European Parliament and the Council and for the organisation of official controls under Regulations (EC); No 854/2004 and No 882/2004 while restricting from Regulation (EC) 8525/2004 and amending Regulations (EC) No 853/2004 and 854/2004	2074/2006	2005
Commission Regulation (EC) No 2073 on microbiological criteria for foodstuffs	2073/2005	2005
Regulation (EC) NO 882/2004 pf the European Parliament and of the Council of 29 April 2004 on official controls performed to ensure the verification of compliance with feed and food law, animal health and animal welfare rules	882/2004	2004
Regulation (EC) No 854 of the European Parliament and of the Council laying down specific rules for the organisation of official controls on products of animal origin intended for human consumption	854/2004	2004
Regulation (EC) No 853 of the European Parliament and of the Council laying down specific hygiene rules for the hygiene of foodstuffs	853/2004	2004
Regulation (EC) No 852 of the European Parliament and of the Council on the hygiene of foodstuffs	852/2004	2004
Commission Decision establishing special health checks for the harvesting and processing of certain bivalve molluscs with a level of amnesic shellfish poison (ASP) exceeding the limit laid down by Council Directive 91/492/EEC	2002/226/EC	2002
Regulation (EC) No 178 of the European Parliament and of the Council laying down the general principles and requirements for food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety	178/2002	2002

Further more, the European Commision has compiled a information sheet (“Farmed in the EU regions”) on the EU rules relevant to local aquaculture businesses shown below (Figure 2) and accessable at https://ec.europa.eu/fisheries/cfp/aquaculture/facts_en

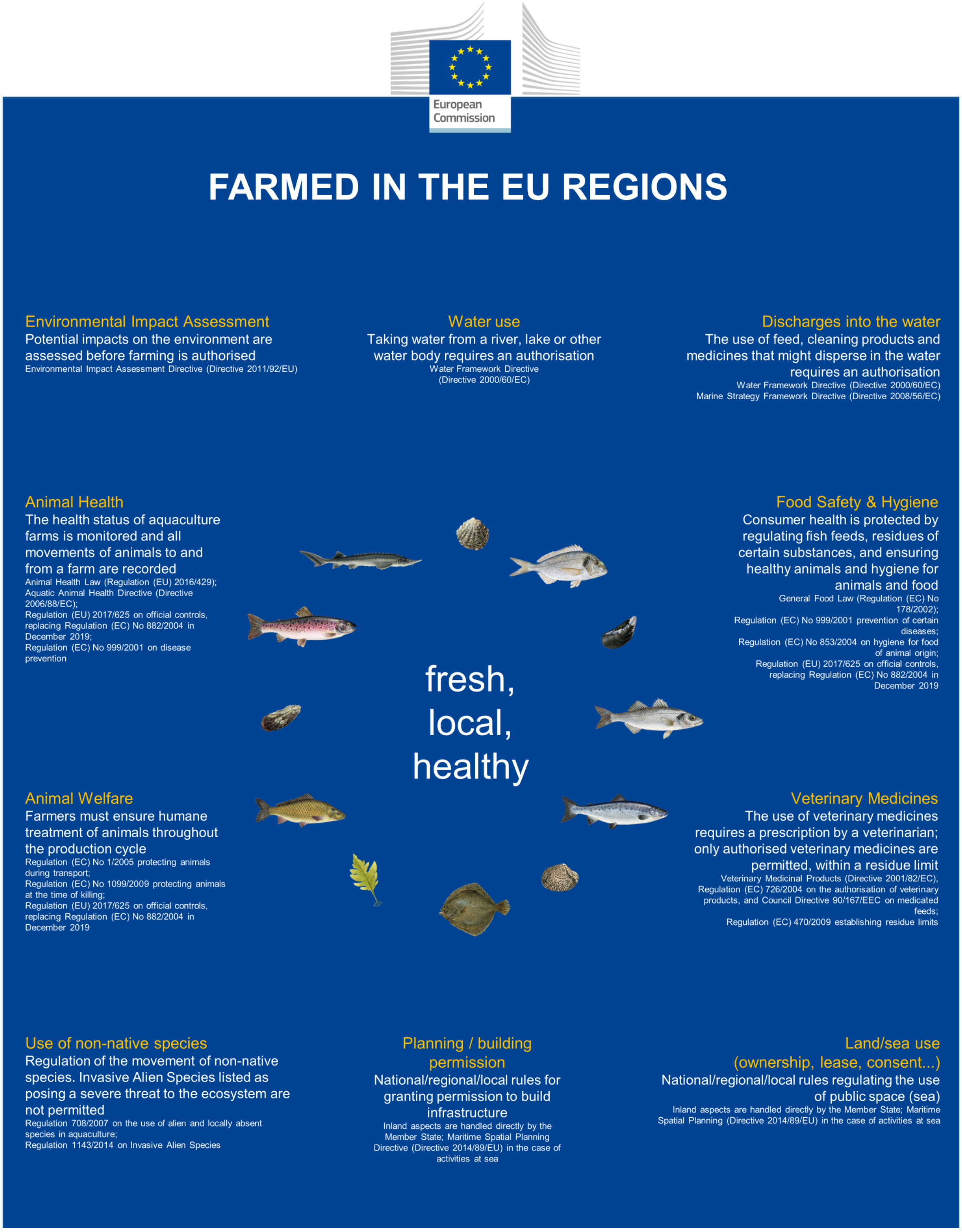

Figure 2. European Commissions fact sheet ”Farmed in the EU regions” on the EU rules relevant to local aquaculture businesses.

In 2016 the European Union established the Aquaculture Advisory Council (AAC) in the framework of the Common Fisheries Policy. This is a stakeholder-led organisation whose main objective is to provide the European institutions and the Member States with recommendations and advice on issues related to the sustainable development of the sector. It is composed of representatives from both the industry and other stakeholders with a special working group on shellfish (and one for finfish and one for horizontal issues). More information on aquaculture in the European Union can be found at: https://ec.europa.eu/fisheries/cfp/aquaculture_en

3.1.2 National regulations in the Baltic Sea region

Nationally, countries have different histories with aquaculture and thus different regulations regarding various aquaculture activities.

- In Denmark the main legislation controlling aquaculture is the Environmental Protection Act, of which the objectives are to ”contribute to safeguarding nature and environment, thus enabling a sustainable social development with respect for human conditions of life and for the conservation of flora and fauna”. This includes precautionary, “polluters pay” and “best available technology” principles. Marine aquaculture is included in an annex listing polluting enterprises, which requires a permit. Authorities have established that marine aquaculture activities require “Environmental Impact Assessments”. Furthermore, aquaculture activities also require permits from the Fisheries Act, in which the EU environmental legislations is a strong component, and regulates management, control and development of fisheries and aquatic resources in Denmark.
- In Sweden, several authorities are involved in the regulation, granting of permits and control of aquaculture activities. For mussel farming, the County administrative Board (Länsstyrelsen) grant permission while the Swedish Food Agency (Livsmedelsverket) handle the control of hygiene and food safety (including monitoring toxins) of mussel farms.
- In Germany, aquaculture (and fishery) activities are observed and overall regulated by the Federal Ministry of Food and Agriculture (Bundesminesterium für Ernährung und Landwirtschaft – BMEL) but permissions and licencing as well as spatial planning is responsibility of the states (Ländersache). Several authorities are involved as e.g. the Waterways and Shipping Office (WSA) and the Federal Agency for Nature Conservation (BfN). Further, the selling process includes risk assessments (e.g. veterinary authority) and in some cases bio certification (eco certification body).
- In Poland the main governmental authority controlling the aquaculture is Główny Inspektorat Weterynaryjny (General Veterinary Inspectorate) supervising activities

on the basis of Ordinance of the Minister of Agriculture and Rural Development of October 14, 2008 on detailed veterinary requirements for conducting business in the aquaculture sector. There are also some EU and national regulations mainly controlling the hygiene and food safety in that sector, among them: Council Directive 2006/88/EC of 24 October 2006 on animal health requirements for aquaculture animals and products thereof, and on the prevention and control of certain diseases in aquatic animals with later implementing documents; national Act of 11 March 2004 on the protection of animal health and combating infectious animal diseases and others. There is not any special regulation regarding the mussel farms.

The issue of site-selection and carrying capacity can be further complicated as natural resources overlap political boundaries. The Baltic Sea is shared by 9 countries with different cultural traditions, economic structures, societal profiles, and legislative frameworks. This complicates the process of setting levels for acceptable impacts both on social and environmental levels. For mussel farming to grow as an important source of food, and as a potential mitigation method in the Baltic Sea, it is important to ensure harmonization of aquaculture regulations within the area. Siting issues must be addressed within region-wide planning through appropriate regulations aimed at cumulative impacts related to production, the environment, and societal requirements.

3.2 The role of marine spatial planning

Planning site-by-site or sector-by-sector has a tendency to fully deal with user-user or user-environmental conflict, and the planning process needs to be reactive. With the European Union having identified aquaculture as a sector for future economic growth, the challenges that emerge from the increasingly competing uses and potential user conflicts are implementing the evaluation of mussel farming siting on the landscape scale, and in relation to the other user interests. Marine spatial planning (MSP) is often suggested as a key to ensure a sustainable use of marine areas (Pınarbaşı et al. 2017). MSP is generally defined as a way to “create and establish a more rational organization of the use of marine space and the interactions between its uses, to achieve social and economic objectives in an open and planned way“ (Douvere 2008). It is a public process which analyses and allocates the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic and social objectives; and the outcome is a comprehensive plan or vision for a marine area. It is used to balance sectorial interests with the aim of improving decision-making for the sustainable use of marine resources. Geographic information system (GIS) technology is often used as a tool by MSP processes to identifying suitable new sites implementing an ecosystem-based management approach. For a comprehensive review of decision support tools in MSP context see Pınarbaşı et al (2017).

Finding areas suitable for mussel farming is more complex than just taking the four carrying capacities into account; it is further complicated by political boundaries. Thus, the MSP process needs to be a cross-border approach taking not only local, but also regional effects into account.

3.3 Nutrient mitigation: implications for site selection

Mussel farming as a mitigation measure does not necessarily need the same requirements of siting as do farms for other uses. Farms with the main aim of extracting nutrients from the environment do not have to produce mussels of the same size, with good appearance, or of as high quality as commercial farms for human consumption. Instead, the farm needs to produce mussels that remove as much nutrients as possible at the lowest cost (incl. labour, equipment etc.) in order to be an efficient tool from a management perspective. Since there are also potential negative impacts on the seafloor under the farm due to sedimentation of biodeposits, this too needs consideration when siting mitigation farms. However, knowledge about the potential abatement efficiency, costs and environmental effects at specific sites are still lacking in the majority of Baltic Sea waters.

4. Decision support tools

With site selection and the planning process being so complex with many potential users and conflicts, tools are being developed to facilitate this process (Falconer et al. 2019). One important type is web-based GIS-tools designed to deal with geographic data. Several different projects have developed such tools that today are important components in national and local planning. They typically give the opportunity to select and deselect certain layers of information, which may be stored internally in the tool or linked from external sources, to provide information of specific objects. Apart from general tools for MSP that include aquaculture as a component, there is also a strong development of more “aquaculture” specific tools aimed at specific aquaculture forms or areas. A detailed assessment of the considerations for GIS-based tools for aquaculture and application of such support tools for aquaculture planning can be found in Falconer et al. (2019). The Eider duck can also contribute to increased biodeposits on the bottom by dislodging mussels from the farm, potentially enhancing unacceptable environmental impacts.

4.1 Tools for site selection and MSP in the Baltic Sea

Baltic Explorer (Figure 3) is an interactive and collaborative web-based Spatial Decision Support System (SDSS) for MSP in the Baltic Sea being developed by the BONUS BASMATI project. It will be a multi-user and multi-platform tool that will allow group work in Maritime Spatial Planning focused on collaborative aspects, which let the users browse data form several different providers. Allowing multiple users to work on the same view from different devices, Baltic Explorer facilitate discussion among different actors. The tool will be published as a free open source software at the end of the BONUS BASMATI project.

Figure 3. Baltic Explorer Spatial Decision Support System for MSP developed within the BONUS BASMATI project.

The Operational Decision-Support System (ODSS) developed by the “Baltic Blue Growth” project is a web-based application (Figure 4) available online, free for all to use that builds on harmonized methodologies and ‘big data’. All on-site evidence of the effects of mussel farming in the Baltic Sea area is integrated and the ODSS features a new spatial modelling framework to show where mussel production and nutrient removal is highest. To avoid potential conflicts with other users, the ODSS portal shows the spatial allocation of other human activities.

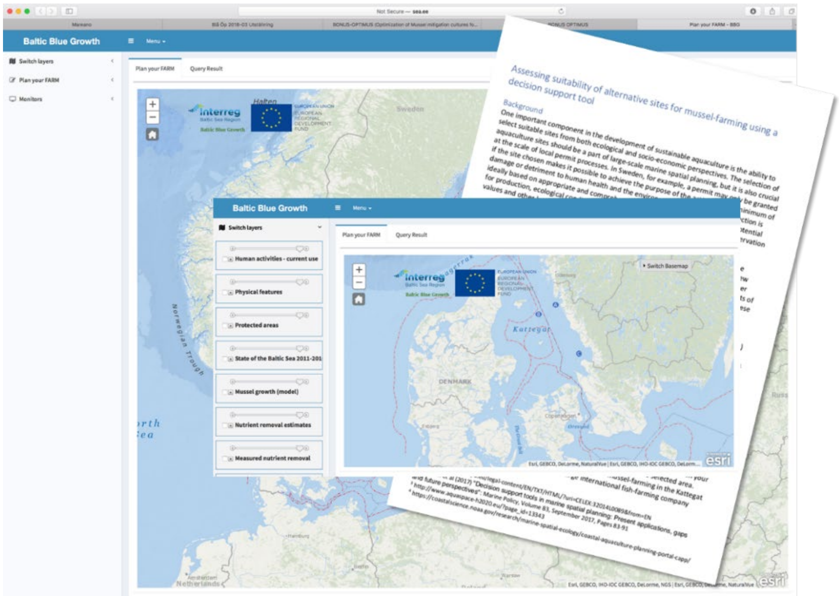

Figure 4. Screen dumps from the Baltic Blue Growth project Operational Decision-Support System tool.

Within the BONUS OPTIMUS project, the integrative spatial multi-criteria web-tool MYTIGATE (Mytilus edulis (Blue Mussel) Mitigation Farm Site Selection Tool) for individual and interactive site-selection is under development. The tool intends to provide guidance for, e.g. political decision makers, within the complex process of Marine Spatial Planning with regard to Mussel Mitigation farming. Currently it includes data from marine areas between Denmark, Germany and Sweden across the Western Baltic Sea (Figure 5). The tool will utilize a stepwise integration of several layers in a geographical information system (GIS) to obtain selection scenarios of suitable area. To support this, a spatial mussel growth model, based on local environmental conditions, is combined with a flexible farm-setup model and other spatial features, limitations, and interests. The considered layers represent aspects (not exhaustively) of all four categories of carrying capacity, discussed in this report (Table 3). The layers can often not exclusively be allocated to only one carrying capacity category. Existing and operated cables and pipelines, for example, limit the physical carrying capacity as anchoring of the farms is not allowed in these areas. The further operation of these and therewith the maintenance of this limitation is, however, a socio-economic interest. Within the stepwise process, users can individually define an area of interest, a selection target (e.g. maximize farm harvest), a farm setup, and choose weights or threshold values for conflict and risk layers (e.g. exclude military areas, exclude areas with >20 m depth, high weight for Marine Protected Areas, low weight for regatta areas). Out of these definitions, a new layer representing ‘farming suitability’ is calculated by excluding respective areas, and reducing the target variable with respect to the number and weights of the accumulated conflict and risk layers. The results of respective site-selection scenarios can be exported. Decision-makers will be able to go through different scenarios and by comparing them, to identify local ideal sites for mussel mitigation farming, as well as local key-challenges, interests, and stakeholders that need to be taken into account to minimize user-user/user-environment conflicts. This is a central intention of Marine Spatial Planning.

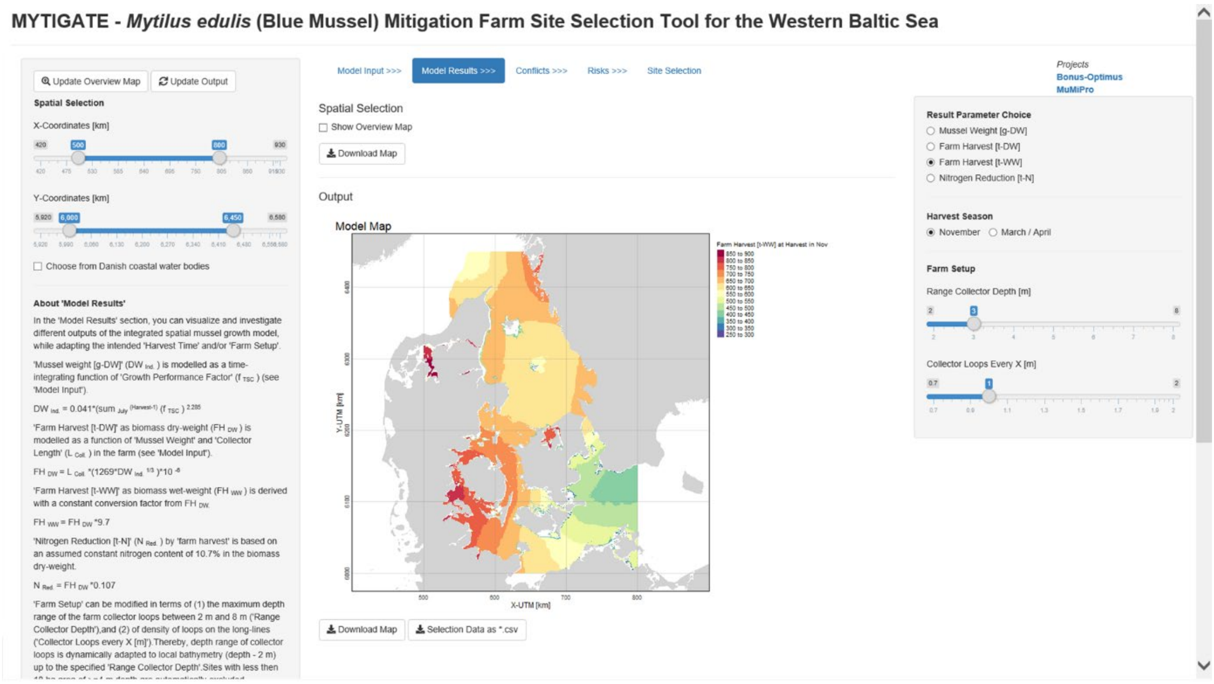

Figure 5. Preliminary view of the BONUS OPTIMUS integrative spatial multi-criteria tool MYTIGATE for individual and interactive site-selection for mussel mitigation farms in the Western Baltic Sea.

Table 3: Layers to be included into the BONUS OPTIMUS integrative spatial multi-criteria site selection tool MYTIGATE for individual and interactive site-selection of mussel mitigation farms in the Western Baltic Sea.

Spatial Layer	Carrying Capacity	Tool Status
Bathymetry	Physical / Production	Implemented
Mussel growth potential	Physical / Production	Implemented
Farm harvest potential	Physical / Production	Implemented
Natural variability of harvest potential	Physical / Production	Planned
Critical flow velocity & Physical Exposure	Physical / Production	Planned
Eider duck abundance	Physical / Production	Planned
Marine Protected Areas	Ecological	Implemented
Impact on benthic environment	Ecological	Planned
Mitigation requirement	Ecological / Social	Planned
Military areas	Physical / Social	Implemented
Major shipping routes and shipping intensity	Physical / Social	Implemented
Anchoring restrictions	Physical / Social	Implemented
Offshore wind farms	Physical / Social	Implemented
Cables & Pipelines	Physical / Social	Implemented
Sediment extraction & dumping	Physical / Social	Implemented
Distance to harbours	Physical / Social	Implemented
Fishing intensity	Social	Planned
Regatta areas	Social	Implemented
Summer house areas	Social	Planned
Farming economy	Social	Planned

4.2 A global outlook

The OceanReport tool (https://oceanservice.noaa.gov/ocean/ocean-reports/) is a web-based interactive tool for ocean mapping and planning of US waters developed as a collaboration between NOAA and the Department of the Interior's Bureau of Ocean Energy Management. It provides professional users and the general public with analyses (incl. maps and graphics) of ocean neighbourhoods to support ocean commerce, energy development and conservation. NOAA's National Ocean Service Office for Coastal Management have developed the Coastal Aquaculture Planning Portal (CAPP, https://coastalservice.noaa.gov/research/marine-spatial-ecology/coastal-aquaculture-planning-portal-capp) which is a toolbox of coastal planning tools designed to assist managers, planners and industry for sustainable aquaculture development (Figure 6).

Figure 6. Appearance of the Coastal Aquaculture Planning Portal (CAPP) web-site.

Within the EU Horizon 2020 project AquaSpace, the open source GIS-Addin tool "AquaSpace Tool" (http://www.aquaspace-h2020.eu) was developed to achieve an effective implementation of MSP for aquaculture by adopting an Ecosystem Approach for Aquaculture (Figure 7). It is one of the first Geographic Information Systems based planning tools empowering an integrated assessment and mapping. The tool allows users to spatially represent and compare risks and opportunities of aquaculture development across several potential sites. The suitability of a site is assessed through a set of indicators grouped in four categories (inter-sectorial, environmental, economic and social) using open source datasets at the European scale. The output of the tool is a pdf- report with general site information, results from all indicators and graphs that allow the user to compare among different scenarios. It also produces a .csv file facilitating the comparison among multiple indicator values, planning trade-offs, and opportunities and risks.

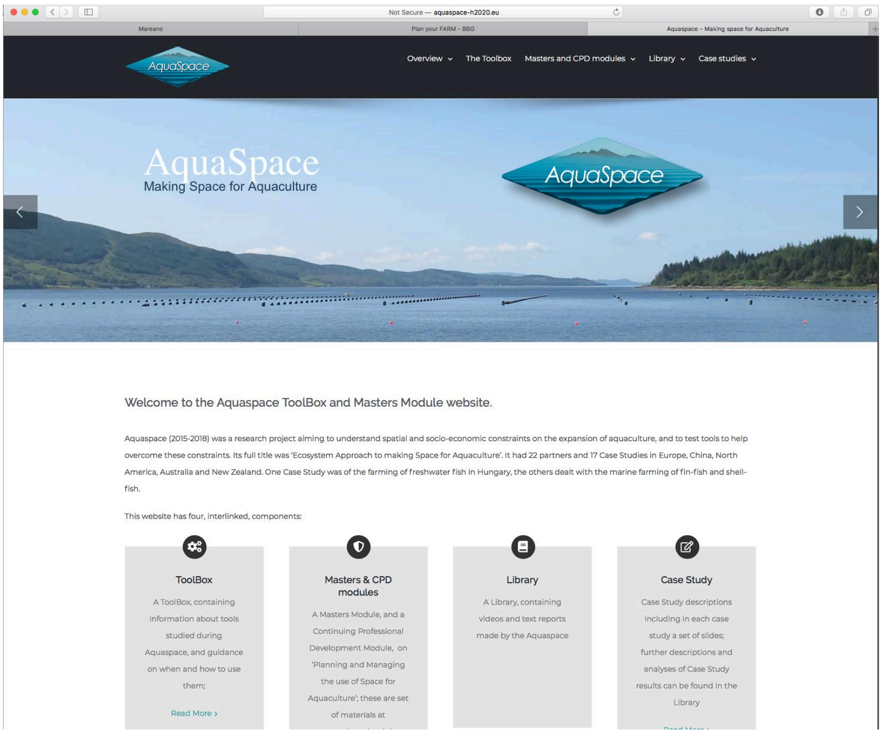

Figure 7. The ”AquaSpace Tool”

4.3 Examples of site-selection for mussel farming in the Baltic

Even though mussel farming is still a relatively new human activity in the Baltic Sea, some projects focusing on spatial planning including site-selection of mussel farming in the area have materialized. For example, the 2014 draft spatial plan for Mecklenburg-Western Pomerania also calls for “spatially compatible” siting of aquaculture operations, such as mussel farming, to minimize environmental impacts. Within the Åland archipelago, the project Baltic Eco Mussel performed a site-selection study for optimal site of mussel farming by comparing 76 sites in 2012 using environmental factors such as water exchange rate, risk of drifting ice and wave exposure. The decision of site suitability were then made on the knowledge of local people in combination with geographical, geological (e.g. bottom structure) and biological (salinity, chlorophyll, nutrients, water exchange etc.) indicators. Furthermore, social and administrative factors such as other interests, and environmental protection were also considered in the process. A similar study was performed by Kraufvelin and Díaz (2013) in the Hanko area in the western Finnish archipelago comparing nine sites. In the Kalmar sound area, the Aquabest project and several small local rural development projects have performed sites selection studies. All these projects, however, mainly compare specific sites rather than developing full coverage maps or strategies for site-selection. Bagdanavičiūtė and co-workers (2018) conducted a GIS-based multi-criteria site selection study for Zebra mussel cultivation in the Curonian lagoon, mainly aimed at finding suitable sites for remediation purposes, proposing a site selection framework for provisional zebra mussel farming. The study combined data from empirical model and remote sensing data to estimate suitability parameters, which were then considered in relation to environmental and socio-economic criteria to find the most suitable sites.

5. Conclusions

Mussel farming in the Baltic Sea is not an easy exercise, from both production and site-selection perspectives. Many studies have shown that the most important decision for successful farming practices is to choose the right site. However, this is a complicated process of identifying areas suitable for the mussels to grow and thrive, and siting that is both economically, socially and environmentally sustainable.

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