

Article

Ecosystem Service Assessments within the EU Water Framework Directive: Marine Mussel Cultivation as a Controversial Measure

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Abstract: To combat the persistent eutrophication in coastal waters, sustainable sea-based measures are recommended. Yet, they are the subject of controversial stakeholder discussion, which hampers the implementation and planning process. The aim of this study is to evaluate if a participatory mapping (PM) approach and ecosystem service assessments (ESA) can be suitable tools within Water Framework Directive (WFD) implementation to support the communication with different target groups to improve and accelerate the planning and realization of new sea-based mitigation measures. We conducted three stakeholder-based PMs to visualize the perception of sea-based mitigation measures in coastal waters and seven different ESAs to investigate the perceptions of different mussel cultivation scenarios as mitigation measures. The PMs showed that ecological measures were preferred. The ESA approach showed that, while experts rated mussel cultivation scenarios positively overall, non-expert stakeholders still seemed skeptical and preferred alternative measures like floating wetlands. The methodological results indicate that PM can be a cost-effective tool to visualize stakeholders' perceptions, but it needs to be applied with an ESA to be beneficial for the WFD implementation process. A web-based ESA improves the discussion with stakeholders and can reveal potential misperceptions and concerns faster and lead to a more focused discussion.

Keywords: ecosystem service assessment; stakeholder; coastal eutrophication; mitigation measures; mussel cultivation



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1. Introduction

Anthropogenic inputs of nitrogen (N) and phosphorus (P) to coastal ecosystems became the primary cause of eutrophication and subsequent coastal ecosystem degradation worldwide, reducing biodiversity and the potential of marine ecosystems to provide valuable ecosystem goods and services [1–3]. However, while marine restoration actions are common, their success rates are highly variable, especially with continuous eutrophication [4]. Various policy frameworks like the European Water Framework directive (WFD) (WFD, 2000/60/EC) and Marine Strategy Framework Directive (MSFD) (MSFD, 2008/56/EC) aim to hinder its progress and to return to a good ecological status. The WFD marks a decisive turn in European water policy, management practices, and restoration trends. After 20 years of implementation in two management cycles, the WFD had been successful in setting up a governance framework for integrated water management for more than 110,000 water bodies in the EU, including transitional and coastal waters. However, as of today, WFD implementation has shown only limited success, especially in coastal waters of the Baltic Sea in regard to counteracting eutrophication and returning to a good ecological status [5]. This can be attributed to several reasons. First, land-based

measures are difficult to implement, since the major nutrient input emerges from diffuse sources like agriculture or from the atmosphere [6]. In addition, water quality improvements are delayed by decades due to leaching from “legacy sources” in soils, sediments, and groundwater [7]. Furthermore, despite management plans, eutrophication in most European coastal waters is expected to increase in the upcoming decades due to human population growth and intensified agriculture practice [8,9].

Within coastal waters, internal mitigation measures, also known as “water-based”, “sea-based”, or “end-of-pipe” solutions, have come into focus to actively support restoration efforts [8,10,11]. As a consequence, the eight European Baltic Sea littoral states signed a ministerial declaration to intensify measures toward the good ecological status and good environmental status of the Baltic Sea, which includes the promotion of sustainable sea-based measures [12]. Recommendations for sea-based measures to combat eutrophication already exist, and measures can be differentiated into hydrological engineering (mechanical measures) (HE), geoengineering (chemical measures) (GG), and ecological engineering (EE) (Duarte and Krause-Jensen, 2018) [9].

In particular, ecological engineering has gained a lot of attention during recent years. The cultivation of filter feeders like the blue mussel (*Mytilus* spp.) as a mitigation measure has been highly discussed and is partly practiced already [13–17]. Longline mussel cultivation can be a sustainable method for producing highly valuable proteins for human consumption or animal stock and simultaneously function as a nutrient retention measure to relieve coastal waters of surplus nutrients [14,18,19]. However, blue mussel cultivation also has its limitations based on its physiological needs (e.g., salinity, temperature, and Chl. a concentration) and can also be associated with negative environmental impacts (e.g., increased bio deposition) [20,21]. Another example for an ecological engineering approach is floating wetlands. Floating wetlands are artificial islands planted with emergent macrophytes to remove excess nutrients from the water via the root system through incorporation into plant biomass and bacterial denitrification [22,23]. Nevertheless, these internal measures are hardly considered within the scope of the implementation of the WFD and are therefore not listed in the recent “Program of Measures” (POM) for the German coastal waters.

The introduction and implementation of internal measures is often hampered, because of several concerns and a lack of information. This is mostly because there is a concern that the mitigation focus will shift from agricultural measures to internal measures, which in turn could potentially increase the agriculture-based nutrient input. Other concerns are competition of space and the fear of potential negative side effects that cannot yet be foreseen [24]. In order to dispel misinformation and concerns of internal mitigation measures, early and comprehensive stakeholder involvement is necessary. Stakeholders typically include governmental, non-governmental, and business representatives, experts (e.g., scientists), landowners, and local users of natural resources. The benefits of early involvement of stakeholders are well-known and include a higher acceptance of measures, which accelerates planning and implementation processes [25]. The WFD encourages active involvement of stakeholders and the public. However, in practice, participatory processes are often restricted to the legally required information supply and consultation. However, especially for the implementation of new sea-based measures, an early and active participation process is crucial to take into account stakeholder concerns and increase acceptance. Here, a holistic approach would be most beneficial to capture the perception of the different stakeholders.

The ecosystem service (ES) concept can be a suitable approach to obtaining a holistic view. While the operationalization of the ES concept in EU environmental policy is already recommended [26,27], no concrete application is provided within the terms of the WFD. As a first step to improve the participation and communication between target groups, ecosystem service assessments (ESAs) have been conducted and used to understand changes caused by new measures to fulfill the WFD [28–30]. The ESA conducted by Schernewski et al. [25] captured experts’ views, disagreements among them, as well

as potential misunderstandings of mitigation scenarios. A final discussion and the opportunity for participants to modify the ESA values ensure that it serves as a promising tool in participation and target group involvement within the coastal planning processes [28]. While former studies gave the first insights into the potential usage of ESAs for the implementation of water quality improvement measures, they lack concrete information about the application within the WFD itself. Therefore, this study aims to evaluate how and at which stage a participatory mapping approach or ESA can be used as a tool to engage stakeholders actively and successfully promote the implementation of new internal mitigation measures within the planning and implementation process of the WFD.

To accomplish this, we (1) first use a participatory mapping approach to identify stakeholder groups' perceptions of and preferences for supportive internal measures, (2) test the use of an ESA with different target groups and different mussel mitigation scenarios, (3) evaluate different assessment methods and their suitability for different target groups, and (4) define recommendations for the use of the tested stakeholder tools within the planning and implementation process of the WFD.

2. Materials and Methods

2.1. Participatory Mapping

In three workshops (Table 1), we used a participatory approach to map the preferential sites for the application of internal measures in European coastal lagoons (Figure 1). Participatory mapping allows the documentation of spatial knowledge [31]. Maps of different European lagoons were fixed to cork walls, and workshop participants could pin flags of different colors to locations where they would regard a certain type of internal nutrient mitigation measure as suitable. The participants could choose the following flags: green for ecological engineering involving vegetation (e.g., floating wetlands and seagrass restoration), blue for ecological measures involving mussel cultivation (e.g., blue mussels and zebra mussel), yellow for mechanical measures (e.g., sediment dredging and sediment capping), red for geoengineering measures, in this case called “chemical measures” for easier differentiation (e.g., phosphorus precipitation with aluminum and oxygenation), and white flags at locations where no internal measures should take place. The participants could also pin memos next to their flags for further explanation.

Table 1. Overview of workshops in which the participatory mapping approach was applied.

Workshop Location	Date	Workshop Background	Target Group	Number of Participants	Science Background	Government Background	Business Background	NGO Background
Stralsund, Germany (PM1)	23 January 2018	Stakeholder workshop on internal nutrient reduction measures	Stakeholder	32	31%	34%	13%	22%
Athens, Greece (PM2)	22 March 2018	8th European Coastal Lagoons Symposium	Stakeholder	22	90%	5%	0%	5%
Klaipeda, Lithuania (PM3)	24 May 2018	Interreg South Baltic Annual Event	Stakeholder	16	50%	25%	0%	25%

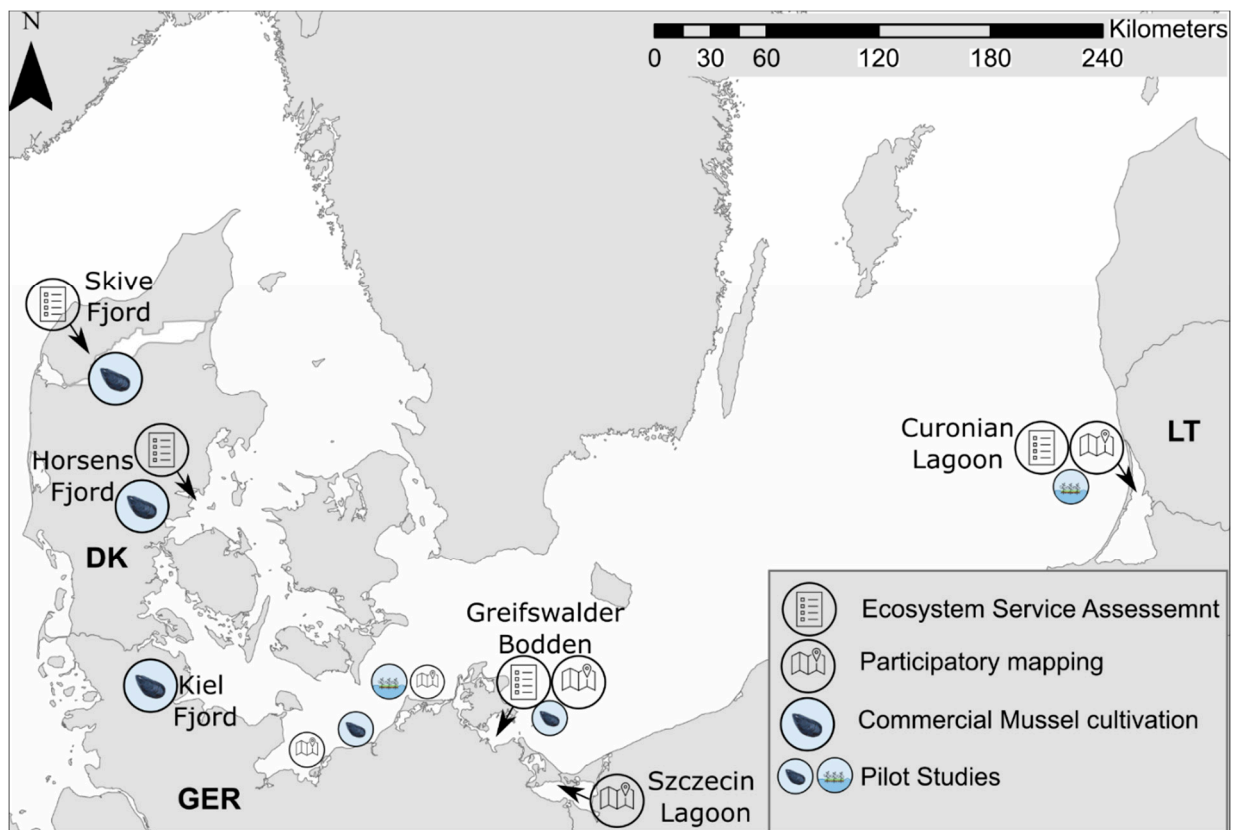


Figure 1. Overview of the study area. The different pictograms show in which countries ecosystem service assessments and participatory mappings were conducted. Furthermore, they indicate which countries already have experience with ecological measures like mussel cultivation or floating wetlands.

2.2. Ecosystem Service Assessments

During seven workshops (Table 2), ESAs were used to compare different ecological internal mitigation scenarios for different inner coastal waters along the Danish, German, and Lithuania Baltic Sea coasts (Figure 1). The participants for the different workshops were experts and graduate students with scientific backgrounds (e.g., in marine ecology, marine aquaculture, or (marine) ecosystem services) and local stakeholders with governmental, non-governmental, or business backgrounds. They were chosen according to their potential involvement during the selection and implementation of new internal mitigation measures in coastal waters. The course of all workshops was always structured in the same way. At the beginning of each workshop, the concept of ecosystem services and their evaluation method was introduced.

The applied ecosystem service assessment is based on the Marine Ecosystem Services Assessment Tool (MESAT) [32]. In general, MESAT assesses changes in ES provision between different time periods [32], but it can also be used for different scenarios [33]. It is based on the Common International Classification of Ecosystem Service (CICES) and can be applied in a qualitative and semi-quantitative way.

Originally, the MESAT contained 31 ESs which were divided into 3 sections: provisioning, regulation and maintenance, and cultural ESs (compare with Inacio et al. [32]). For the comparison of different mussel mitigation scenarios, only ESs which were relevant to mussel cultivation were chosen for the assessment. The resulting 25 ESs are listed in Table 3. We rated the change in the ES provision (caused by the implementation of a measures) based on 11 scoring classes ranging from −5 (very high decrease) to +5 (very high increase). No change was rated as 0. For the stakeholder assessment (11.9.2019), which included a high number of stakeholders with governmental, business, and NGO backgrounds (Table 2),

the number of ESs was further reduced from 25 to 8 ESs to reduce the duration of the assessment and make it more comprehensible. Adjusted to the assessment, the scoring options were reduced to 6 classes ranging from -3 (very negative change) to $+3$ (high positive change).

Table 2. Overview of Ecosystem service assessment workshops and applied scenarios and methods.

Workshops	Target Group	No. of Participants	Scenarios	Sites	Assessment Approach	No. of ESs	Place	Date	Discussion Strategy
1	Experts	12	Commercial MF vs. Beach MF	Curonian Lagoon	Paper-based	25	Klaipeda, Lithuania	27 September 2018	After the assessment
2	Stakeholders	4	Commercial MF vs. Beach MF	Curonian Lagoon	Paper-based	25	Nida, Lithuania	10 January 2018	After the assessment
3	Graduate Students	15	Commercial MF vs. Beach MF	Greifswald Bodden	Web-based	8	Warnemünde, Germany	7 January 2019	After every single ES
4	Experts	11	Commercial MF vs. IMTA	Limfjord; Horsens Fjord	Web-based	25	Ranum, Denmark	22 August 2019	After every scenario
5	Graduate Students	5	Commercial MF vs. Beach MF	Curonian Lagoon	Web-based	25	Klaipeda, Lithuania	9 December 2019	After every ES division
6	Stakeholders	16	Beach MF vs. Floating Islands	Greifswald Bodden	Web-based	8	Stralsund, Germany	11 September 2019	After the assessment
7	Graduate Students	16	Beach MF vs. Floating Islands	Greifswald Bodden	Web-based	8	Kiel, Germany	12 October 2019	After every single ES of the assessment

The scenarios presented include a realistic but theoretical description of the mitigation measure as well as information about the local environment (e.g., information on ecological status of coastal waters, tourism activities, and industrial infrastructure).

Altogether, two different assessment methods were tested: the paper-based approach used by Schernewski et al. [25] and a web-based application. In the paper-based assessment, the 25 ESs and their descriptions were presented as a table. The assessment of a single ES had to be entered by hand. To complete the assessment, participants had about 30 min. The web-based assessment was conducted with the tool “Mentimeter”. Mentimeter (www.mentimeter.com) (accessed on 9 December 2021) is originally used for educational purposes and is a Student Response System (SRS) voting tool [34]. SRSs should help to encourage participants to engage in discussions and through their portable devices (e.g., mobile phones, laptops, or tablets). Mentimeter enables quick and anonymous feedback to both quantitative and qualitative questions. Using their devices, applicants submit their answers via a webpage, and the responses are instantaneously and anonymously displayed on a screen [34].

During the assessments, different strategies were also tested to improve the common understanding of the assessed ESs. Therefore, discussions at different stages of the assessment were used to prevent a false rating which could be based on a misunderstanding or misinformation. After the discussion, participants had the chance to adjust their values if they were willing. Discussions were conducted after the assessed scenario between ES divisions and after single services.

2.3. Sites and Application

Within the ESA, we concentrated on ecological measures consisting of different mussel cultivation strategies as well as the application of floating artificial wetlands (Figure 2). The different ecological measures were based on strategies to mitigate nutrients and increase

water transparency, which can be found in the current literature (see description). A detailed description of the measures is given below.

Table 3. Ecosystem service classes and the associated descriptions which were chosen for the ecosystem service assessment.

Division	Ecosystem Service Classes	Description
Provisioning	Wild plant outputs	Harvest and number of species (e.g., algae) for consumption
	Wild animal output	Harvest and number of species (e.g., fish) for consumption
	Aquaculture	Total and key market species landings (e.g., fish seafood)
	Materials for processing and agriculture	Harvested amount and value (fodder, fiber, seaweed, and fertilizer)
	Physical and bioenergy	Amount of abiotic and biotic energy resources (wind or wave energy, solar panels, and methane production)
	Navigation and waterways	Shipping (international ferries and cruisers) and water-based local public transport
	Harbors and maritime industries	Areas with sea access
Regulation and Maintenance	Burial of nutrients and organic matter	Sediment accumulation rate
	Nutrient removal	N-denitrification
	Primary productivity	Nutrient and Chl.a concentration
	Water transparency	Secchi depth
	Matter transformation	Water residence time
	Oxygen provision	(Bottom) oxygen concentration (above 6 mg/L)
	Pest control	Potentially harmful algae blooms and number of alien species
	Nursery grounds	Size and number of nursery areas
	Habitat biodiversity	Size and number of habitats
	Mass stabilization	Extension of macrophyte habitats
Cultural	Flood protection	Buffering capacity for high water levels, wave attenuation, and current reduction
	Bathing and sunbathing	Water transparency and shell accumulation
	Recreation and water sports	Water sports and recreational activities like surfing, paddling, sailing, and angling
	Aesthetic experience	Number of seaside visitors looking for enjoyment provided by land and sea ecosystems
	Attractiveness for seaside housing	Length of shoreline, number of flats with a sea view or access, and floating houses
	Experimental use	Participation in biota-related activities (bird watching and iconic species watching)
	Scientific and educational	Scientific and educational publications, documentaries, and exhibitions
	Economic development	Number of jobs and amount of total income

2.3.1. Commercial Mitigation Mussel Farm

The concept of the mitigation mussel farm is based on mass balance principles of inorganic nutrients which are available in the marine environment and are transformed into phytoplankton, which is then immobilized by the filter feeding activity of suspended mussels [35]. Subsequently, when the mussels are harvested, the nutrients stored within the mussels are removed from the marine environment [13]. Harvested mussels can be used as a high-quality protein source and can be sold commercially. Since the mitigation cultivation strategy differs from the cultivation for human consumption, mussel products need to be sold for other purposes (e.g., mussel meal or fertilizer).

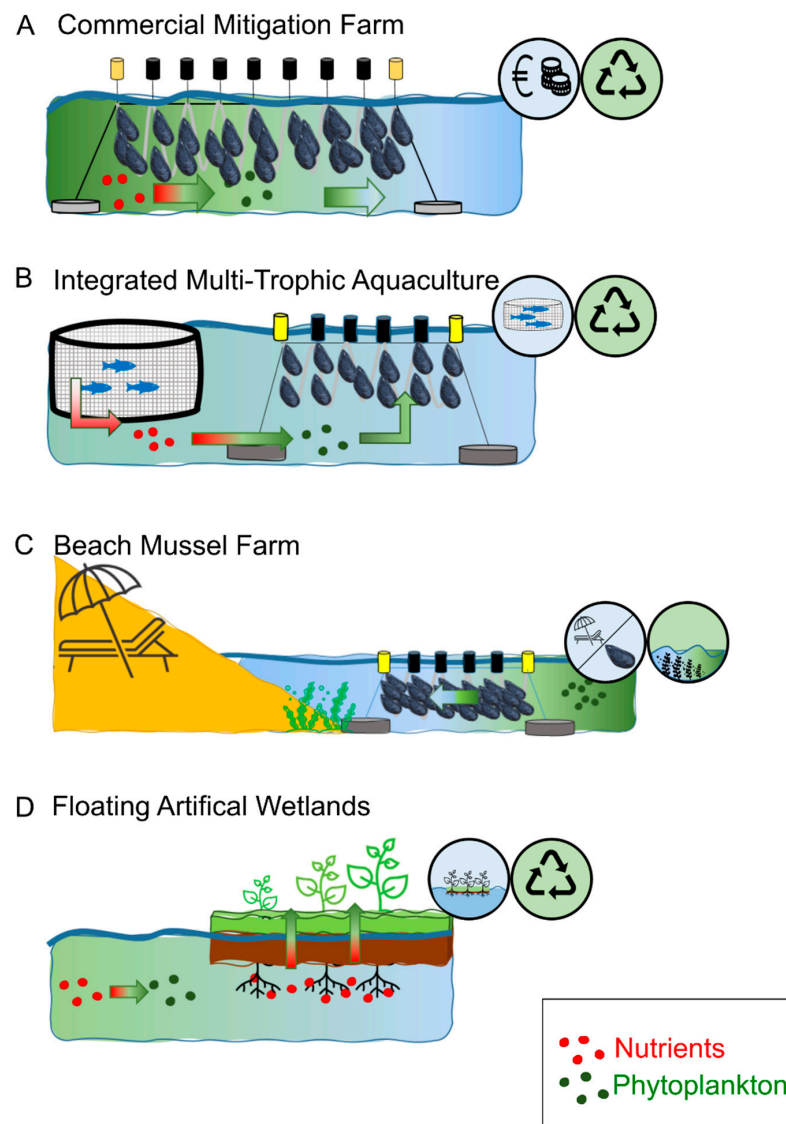


Figure 2. Different ecological measures consisting of different mussel farm strategies (A–C) and the example of an artificial floating wetland (D) (not to scale).

2.3.2. Integrated Multi-Trophic Aquaculture

Integrated multi-trophic aquaculture (IMTA) is the co-culturing of different species that can be used to reduce the nutrient emissions from marine fish farms [36]. The concept of IMTA uses a similar mass balance principle approach as the mitigation mussel farm strategy. Instead of dissolved nutrients emerging from land, here, the dissolved nutrients from one species (e.g., fish) are utilized by the extractive species (e.g., seaweeds or mussels) and removed from the system through harvesting [37]. However, mussels capture nutrients in particulate form, primarily as phytoplankton, and not directly capturing the dissolved nutrients released from the fish farm. In order to compensate nutrients emerging from fish farms, one option is to place mussel farms in close proximity to the fish farms or to locate mussel farms in coastal areas affected by nutrient transport from fish farms.

2.3.3. Beach Mussel Farm

The objective of the beach mussel farm is to improve the water transparency in bathing areas to increase the attractiveness for beach users. At the same time, near the shore, submerged macrophytes also benefit from the increased water transparency and the

associated light availability. As a result, submerged macrophytes are able to spread and stabilize the sediments, further binding nutrients and increasing water transparency [28].

2.3.4. Floating Artificial Wetlands

Floating artificial wetlands are a “phyto-technology”, where emergent macrophytes grow on a buoyant platform and support remediation of eutrophication on several levels [38]. On the one hand, roots in the water column directly adsorb nutrients and incorporate them into plant tissue through biosynthesis. On the other hand, a biofilm on the roots enhances bacterial denitrification. In addition, floating islands attenuate wave energy and water flow and are consequently able to enhance particle settling and nutrient burial [38–40]. Floating wetlands with native emergent macrophytes were tested for the first time in Baltic lagoons in 2018 [39,40] and turned out to be a valuable refuge for aquatic fauna such as the endangered eel [33].

Each measure was formulated as a scenario, and two scenarios were always evaluated for one target area (Figure 3). Within the Danish coastal waters (Limfjord and Horsens Fjord), a commercial mitigation approach (Limfjord) and the IMTA approach (Horsens Fjord) were formulated as scenarios (Figure 3 (1)). For the Curonian Lagoon, a commercial mussel farm as well as a beach mussel farm were set as scenarios. Due to the reduced salinity of the Curonian Lagoon, zebra mussels were cultivated (Figure 3 (2)). For the German coastal waters, the Greifswalder Bodden was used as the scenario site. Here, a beach mussel farm and floating wetland scenario were assessed (Figure 3 (3)).

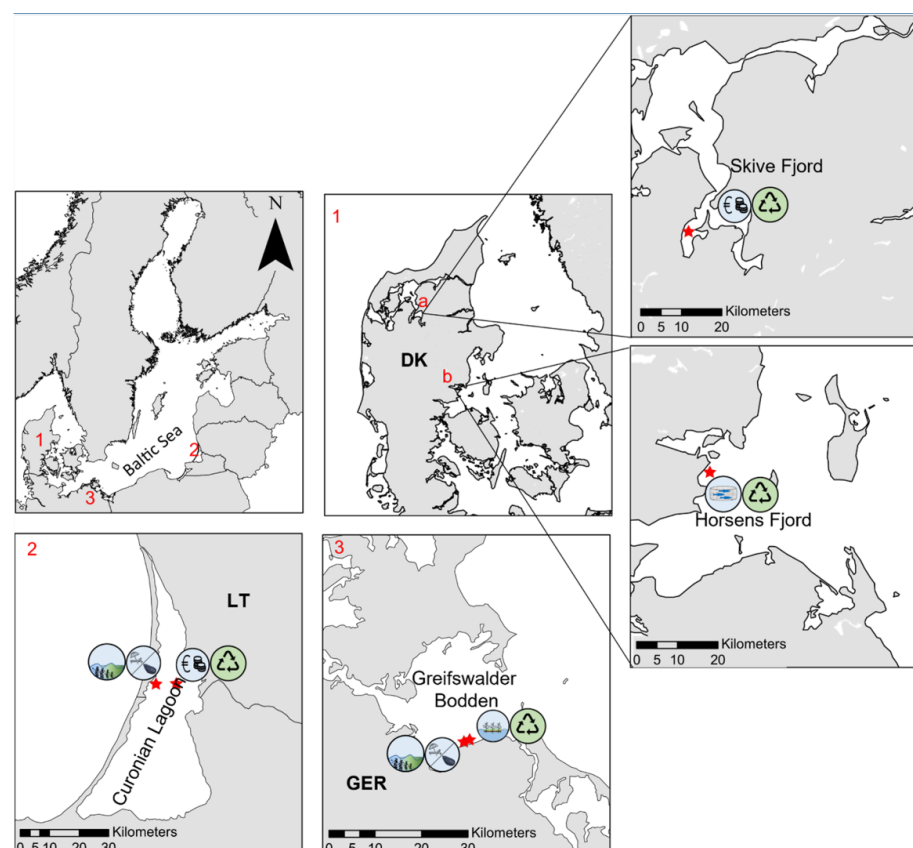


Figure 3. Different scenarios and their sites (five-pointed star), which were assessed in different ESAs. (1) Two mussel farm scenarios in Danish coastal waters: (a) commercial mitigation farm in the Skive Fjord vs. (b) the IMTA approach in the Horsens Fjord; (2) two mussel farm scenarios in the Curonian Lagoon: commercial mitigation farm vs. beach mussel farm; and (3) beach mussel farm scenario vs. floating macrophyte islands in Greifswalder Bodden.

3. Results

3.1. Participatory Mapping

The participatory mapping showed that the EE measures were the preferred choice compared with the HE and GE approaches (Figure 4, Table 4). When accumulating the results of all three workshops, the EE measures involving macrophytes (44%) and mussels (22%) were pinned the most. The notion that no mitigation measure was necessary or wanted was pinned only 7% of the time in comparison. It should be noted that only the selection “no measures” was made at the German workshop in Stralsund.

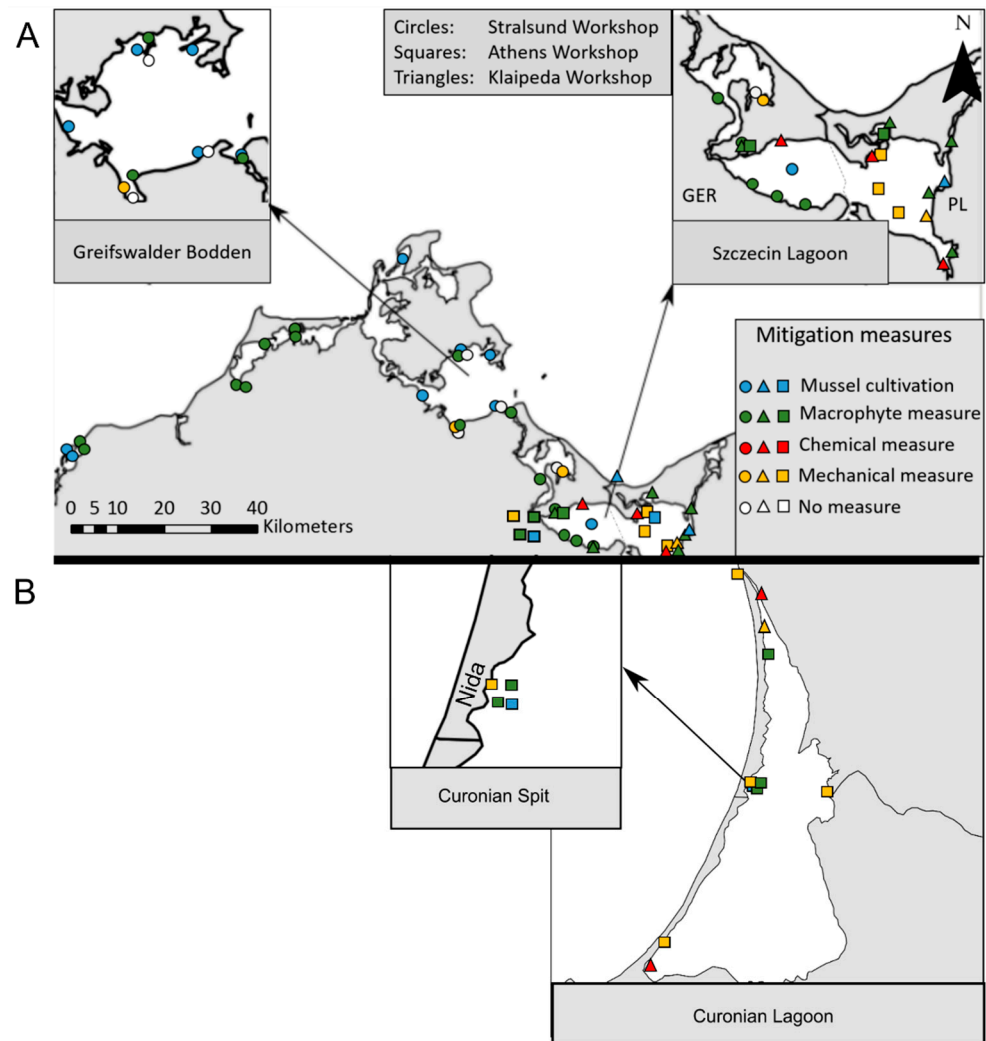


Figure 4. Locations of the flags for potential installation sites of sea-based measures for nutrient removal which the participants pinned during the workshops in Stralsund, Germany (23 January 2018; symbol: circle), in Athens, Greece (22 March 2018; symbol: square), and in Klaipeda, Lithuania (24 May 2018; symbol: triangles). (A) German and Polish coastal waters, with focus on the Greifswalder Bodden and the Szczecin Lagoon. (B) Lithuanian coastal waters, with focus on the Curonian Spit.

Comparisons between the different nationalities of the participants were difficult to conduct, as the workshops in PM2 and PM3 were conducted on an international level (Table 1), and the participants involved were of different nationalities. However, a comparison could be made between the different results from PM1 and PM3, as local stakeholders (non-scientists: Germany = 69%; Lithuania = 50%) participated in both workshops. The comparison shows that the participants in Lithuania showed a much greater focus on the

GE (33%). The mussel cultivation approach was, on the other hand, less favored compared with the results from Stralsund.

Table 4. Amount of flags pinned for potential installation sites for different internal nutrient removal measures. The round brackets show the percentages per workshop, the square brackets show the percentage distribution across all workshops, and the curved brackets the total share of all measures pinned.

Measure	Flag Color	Stralsund Workshop (PM1)	Athens Workshop (PM2)	Klaipeda Workshop (PM3)	Total Amount
Macrophyte measure (EE)	Green	15 (50) [58]	5 (31) [19]	6 (40) [23]	26 {44}
Mussel measure (EE)	Blue	9 (30) [69]	2 (13) [15]	2 (13) [15]	13 {22}
Mechanical measures (HE)	Yellow	2 (7) [18]	7 (44) [64]	2 (13) [18]	11 {19}
Geoengineering measures (GE)	Red	0	0	5 (33) [100]	5 {9}
No measure	White	4 (13) [100]	0	0	4 {7}
Sum		30	14	15	59

However, if we compared the results of the different workshops according to their stakeholder compositions, we saw that there were also differences in the choice of measures (Table 4). In PM2, where 95% of the participants were scientists, ecological and mechanical methods were equally pinned. During PM1, where 69% of the participants consisted of non-scientists, the ecological methods (macrophytes (50%) > mussels (30%)) were predominated. At four locations, the wish that no measures at all be implemented was stated (Figure 4). During PM3, which consisted of 50% scientists and 50% other stakeholders, the ecological measures were also preferred, but the use of GE measures (chemical applications) also had a share of 33%.

With the current conducting method, no homogeneous result could be obtained, and no recommendation could be derived. In order to achieve a homogenous result, it is necessary to define or provide homogenous background information (e.g., specify the target area, potential interactions with the environment, or define nutrient reduction scenarios). Here, a combination of the ESA approaches would be beneficial, since it supplies scenario and background information and guides the participants to reflect about possible environmental interactions.

3.2. Ecosystem Service Assessments

3.2.1. Expert-Based ESA of the Mussel Mitigation Approach in Different Coastal Systems

The comparison of the two expert-based ESAs focusing on commercial mitigation mussel farms in the coastal waters of Lithuania and Denmark (Table 5) shows that the expert groups of both countries assessed the changes of provisioning ESs by commercial mitigation mussel farming quite similarly and slightly positively (average increase of ESs by +1) (Table 5). Both groups were in agreement that the mussel farm scenarios had no effect on the ES “Physical and bioenergy”.

For regulating ESs, the most deviations between the two expert groups could be seen between the ESs “Burial of nutrients and organic matter”, “Primary productivity”, and “Oxygen provision”. In contrast, the experts from Lithuania rated the changes in “Burial of nutrients and organic matter” slightly positively (mean value +1) and with no changes in “Primary productivity”. The change in “Oxygen provision” was surprisingly rated negatively by Lithuanian experts (mean value = −2). Overall, it seems that experts in Denmark rated the changes in the regulating ESs higher compared with the experts in Lithuania.

Within the division of cultural ESs, slight differences in ratings occurred between both expert groups for the ESs “Bathing and sunbathing”, “Recreation and water sports”, and “Experimental use”. Here, the expert group in Denmark rated the changes in the above mentioned ESs slightly more positively than the expert group from Lithuania.

Overall, and despite their different levels of experience with the mussel cultivation practice, both expert groups from Denmark and Lithuania rated the changes to the ESs by a commercial mussel farm scenario slightly positively overall. The results also show that the greatest and considerable disagreements in the rating of changes to ESs appeared for regulating ESs. The results show that an ESA can also be used to identify uncertainties and where a wider discussion is needed.

Table 5. Comparison of two ecosystem service assessments assessing the effects (changes) of large-scale commercial mitigation mussel farms based in Lithuanian and Danish coastal waters. The assessment was conducted by experts. The mean and median values were calculated based on the aggregated number of ratings.

	Commercial Mitigation Farm (Lithuania)			Commercial Mitigation Farm (Denmark)			Diff. in Mean	Diff. in Median
	Mean	Median	St. Dev.	Mean	Median	St. Dev.		
Provisioning Ecosystem Services								
Wild plant outputs	0	0	1.8	1	1	1.0	1	1
Wild animal outputs	2	2	1.2	2	2	1.0	0	0
Aquaculture	2	1	1.5	3	3	1.5	2	2
Materials for processing and agriculture	1	1	1.1	1	1	1.2	0	0
Physical and bioenergy	0	0	1.3	0	0	0.3	0	0
Navigation and waterways	−1	−1	2.3	−1	−1	0.9	0	0
Harbors and maritime industries	0	0	2.2	1	1	1.3	1	1
Regulating Ecosystem Services								
Burial of nutrients and organic matter	1	1	1.8	−1	−1	1.4	−2	−2
Nutrient removal	1	2	2.0	3	3	1.8	1	1
Primary productivity	0	0	2.4	−2	−2	0.7	−2	−2
Water transparency	2	2	1.0	3	3	1.3	1	1
Matter transformation	1	1	1.3	0	0	0.8	−1	−1
Oxygen provision	−2	−3	2.4	1	1	1.4	3	4
Pest control	0	0	2.5	1	0	1.1	1	0
Nursery grounds	1	1	1.8	2	2	1.4	1	1
Habitat diversity	2	2	1.9	2	2	0.8	0	0
Mass stabilization	1	1	1.7	2	2	0.9	1	1
Flood protection	1	0	1.4	1	0	1.0	0	0
Cultural Ecosystem Services								
Bathing and sunbathing	0	0	0.9	2	2	1.2	2	2
Recreation and water sports	−1	−1	2.0	0	0	1.5	1	1
Aesthetic experience	0	0	1.6	0	0	1.1	0	0
Attractiveness for seaside housing	0	0	1.0	0	0	1.2	0	0
Experiential use	2	2	1.6	1	0	2.0	−1	−2
Scientific and educational	3	3	1.3	2	2	1.7	−1	−1
Economic development	2	2	1.1	2	2	1.4	0	0

3.2.2. Expert ESA Application in Danish Coastal Waters

The expert group in Denmark (with background knowledge about blue mussel cultivation) compared a commercial mussel farm and an IMTA approach (Figure 3 (1)). The results of the web-based ESA show that the majority of the provisioning ES was positively influenced by both mussel farm scenarios. This can be explained by the fact that the compensation of nutrients emerging from marine finfish cultivation increases the capacity of the additional potential marine finfish aquaculture. This fact also explains the deviating rating

of the ES “Navigation and waterways” (IMTA: mean score = −1; commercial mitigation Farm: mean score = −1). Due to the higher aquaculture practice, navigation and potential waterways of marine traffic might be more restricted.

When comparing the ratings of the regulating ESs, experts assessed the “Burial of nutrients” (diff. in mean = −3), “Primary productivity” (diff. in mean = +3), and “Water transparency” (diff in mean = −2) differently. Other services were rated either with no change or slightly differently, with a deviation in the mean value of ± 1 (Table 6).

Table 6. Comparison of two mussel farm applications assessing the effects (changes) on ecosystem services. The mussel farm applications included an IMTA approach (Horsens Fjord) and a large-scale commercial mitigation mussel farm (Skive Fjord), both located in Danish coastal waters. The assessment was conducted by experts with mussel cultivation backgrounds. The mean and median values were calculated based on the aggregated number of ratings.

Provisioning Ecosystem Services	Commercial Mitigation Farm (Denmark)			IMTA (Denmark)			Diff. in Mean	Diff. in Median
	Mean	Median	St. Dev.	Mean	Median	St. Dev.		
Wild plant outputs	1	1	1.0	1	1	1.0	0	0
Wild animal outputs	2	2	1.0	2	2	0.9	0	0
Aquaculture	3	3	1.5	4	4	0.9	1	1
Materials for processing and agriculture	1	1	1.2	2	2	1.3	1	1
Physical and bioenergy	0	0	0.3	0	0	0.3	0	0
Navigation and waterways	−1	−1	0.9	−1	−2	1.1	0	−1
Harbors and maritime industries	1	1	1.3	1	1	1.0	0	0
Regulating Ecosystem Services	Mean	Median	St. Dev.	Mean	Median	St. Dev.	Diff. in Mean	Diff. in Median
Burial of nutrients and organic matter	−1	−1	1.4	0	0	2.1	1	1
Nutrient removal	3	3	1.8	0	0	1.7	−3	−3
Primary productivity	−2	−2	0.7	1	1	0.9	3	3
Water transparency	3	3	1.3	1	0	1.1	−2	−3
Matter transformation	0	0	0.8	0	0	0.7	0	0
Oxygen provision	1	1	1.4	0	0	0.5	−1	−1
Pest control	1	0	1.1	−1	−1	1.5	2	−1
Nursery grounds	2	2	1.4	1	1	1.8	−1	−1
Habitat diversity	2	2	0.8	1	1	1.3	−1	−1
Mass stabilization	2	2	0.9	1	1	1.5	−1	−1
Flood protection	1	0	1.0	1	0	1.0	0	0
Cultural Ecosystem Services	Mean	Median	St. Dev.	Mean	Median	St. Dev.	Diff. in Mean	Diff. in Median
Bathing and sunbathing	2	2	1.2	0	0	1.4	−2	−2
Recreation and water sports	0	0	1.5	−1	−1	1.3	−1	−1
Aesthetic experience	0	0	1.1	−1	−1	1.2	−1	−1
Attractiveness for seaside housing	0	0	1.2	−1	−1	1.4	−1	−1
Experimental use	1	0	2.0	0	0	1.2	−1	0
Scientific and educational	2	2	1.7	3	3	1.9	1	1
Economic development	2	2	1.4	2	2	1.5	−1	0

The assessment of the cultural ES also showed mostly little deviation between the ratings (diff. in mean = ± 1). Only the ES “Bathing and sunbathing” showed a stronger deviation (diff in mean = −2) (Table 6). The results indicate that a commercial mitigation farm as well as an IMTA approach had rather a positive affect or no implications at all on the cultural ES.

These results show that an ESA can not only be beneficial for experts which have less or no experience with mussel cultivation but also be a good supplement for discussions of mussel cultivation. It is suitable to evaluate and discuss the perception of strengths and weaknesses of different mussel farm set-ups.

3.2.3. Expert-Based ESA Application in the Curonian Lagoon

The effects on the provisioning ESs were rated mostly positive by the expert group in Lithuania. Only the ES “Navigation and waterways” was rated slightly negative for both mussel farm applications (Table 7). The same was true for the assessment of the regulating ES. Only the ES “Oxygen provision” was assessed with a negative change (Beach mussel farm: mean value = −1; Commercial mitigation farm = −2). Additionally, the Lithuanian experts assessed that for the beach mussel farm, the ES “Pest control” would decrease slightly (mean value = −1).

Table 7. Comparison of two mussel farm applications assessing the impacts on ecosystem services. The mussel farm applications are a beach mussel farm and large-scale commercial mitigation mussel farm both located in the Curonian Lagoon. The assessment was conducted by experts. The mean and median values were calculated based on the aggregated number of ratings.

	Beach Mussel Farm (Lithuania)			Commercial Mitigation Farm (Lithuania)				
Provisioning Ecosystem Services	Mean	Median	St. Dev.	Mean	Median	St. Dev.	Diff. in Mean	Diff. in Median
Wild plant outputs	0	0	1.8	0	0	1.8	0	0
Wild animal outputs	2	2	1.1	2	2	1.2	0	0
Aquaculture	1	1	1.0	2	1	1.5	−1	0
Materials for processing and agriculture	1	1	0.9	1	1	1.1	0	0
Physical and bioenergy	1	0	1.4	0	0	1.3	0	0
Navigation and waterways	−1	−1	1.1	−1	−1	2.3	1	0
Harbors and maritime industries	0	0	1.5	0	0	2.2	0	0
Regulating Ecosystem Services	Mean	Median	St. Dev.	Mean	Median	St. Dev.	Diff. in Mean	Diff. in Median
Burial of nutrients and organic matter	1	1	1.6	1	1	1.8	0	0
Nutrient removal	1	1	1.8	1	2	2.0	−1	−1
Primary productivity	0	0	1.9	0	0	2.4	0	0
Water transparency	2	3	1.0	2	2	1.0	0	1
Matter transformation	1	0	1.1	1	1	1.3	−1	−1
Oxygen provision	−1	−2	2.2	−2	−3	2.4	0	1
Pest control	−1	0	2.0	0	0	2.5	0	0
Nursery grounds	1	1	1.5	1	1	1.8	0	0
Habitat diversity	2	2	1.3	2	2	1.9	0	0
Mass stabilization	1	0	1.8	1	1	1.7	0	−1
Flood protection	1	1	1.5	1	0	1.4	0	1
Cultural Ecosystem Services	Mean	Median	St. Dev.	Mean	Median	St. Dev.	Diff. in Mean	Diff. in Median
Bathing and sunbathing	1	1	1.7	0	0	0.9	0	1
Recreation and water sports	−1	−2	2.4	−1	−1	2.0	0	−1
Aesthetic experience	−1	−1	2.2	0	0	1.6	−1	−1
Attractiveness for seaside housing	0	0	1.8	0	0	1.0	0	0
Experimental use	2	2	1.4	2	2	1.6	0	0
Scientific and educational	3	3	1.2	3	3	1.3	0	0
Economic development	2	2	1.5	2	2	1.1	0	0

Within the division cultural ES, the services “Recreation and water sports” were rated slightly negatively (mean value = -1) for both application scenarios. The experts also assessed that for the beach mussel farm application, the overall “Aesthetic experience” would change slightly negatively (mean value = -1). Opposite to this, the ESs “Experimental use”, “Scientific and educational”, and “Economic development” were rated positively for both application scenarios.

In comparison with the expert group in Denmark, the expert group in Lithuania did not show as much deviation in the assessment between the two scenarios, even though the scenarios were very contradictory (diff. in mean = ± 1 or no change over all divisions).

3.2.4. Non-Expert-Based ESA Application in the Greifswalder Bodden

When non-expert stakeholders compared the mussel mitigation approach to floating wetlands, the floating wetlands received a slightly better rating in regulation and cultural ES provision (Table 8). The largest differences between the two ecological measures were in the cultural division. Floating wetlands are perceived as aesthetic landmarks, enriching the local recreation and tourism values of the region. This depicted a clear contrast to the mussel farm scenario, where the impact on the aesthetic experience was perceived negatively and entailed potential conflict.

Table 8. Comparison of a mussel farm application and floating wetland, assessing the impacts on ecosystem services. The mussel farm applications were a beach mussel farm and floating wetland, both located in Greifswalder Bodden. The assessment was conducted by local non-expert stakeholders. The mean and median values were calculated based on the aggregated number of ratings.

Provisioning Ecosystem Services	Beach Mussel Farm (Germany)			Floating Wetlands (Germany)			Diff. in Mean	Diff. in Median
	Mean	Median	St. Dev.	Mean	Median	St. Dev.		
Wild food	1	1	1.3	1	1	0.8	1	0
Livestock and aquaculture	2	2	0.9	1	0	0.9	-1	-2
Crop plants	0	0	0.2	1	1	1.1	1	1
Regulating Ecosystem Services								
Nutrient regulation	1	1	1.0	1	1	0.8	0	0
Water quality improvement	2	1	0.8	1	1	0.8	0	0
Biodiversity and habitats	2	1	1.2	2	3	0.7	1	2
Cultural Ecosystem Services								
Recreation and tourism	0	-1	1.5	2	2	1.1	2	3
Landscape aesthetics	-1	-1	1.4	2	1	1.0	2	2

3.2.5. Comparison between Different Assessment and Discussion Strategies

The application of the two assessment strategies—paper-based vs. web-based—showed that the web-based application could benefit the assessment speed as well as the level of engagement. During the web-based assessment, it was noticed that the visualization of the results in real time as well as a set time limit for responding forced participants to answer more rapidly. The instant display of ratings enabled different discussion strategies (e.g., after every single ecosystem service or ecosystem service division).

In contrast, during the paper-based assessment, the participants tended to overthink their ratings, increasing the total time of the assessment or skipping the assessment of single services. During the paper-based method, real-time visualization was hard to accomplish, disabling different discussion strategies. The display of the preliminary results was also timely, since the results had to be transferred to a computer and had to be visualized first.

The use of different discussion strategies has shown that the strategy of discussing each division individually (assessment and discussion of the provisioning ESs of a first scenario followed by the assessment and discussion of the provisioning ESs of the second

scenario) was the most suitable to generate a common understanding (overall changes after the discussion: 26%) and led to few changes in the assessment of the second scenario (overall changes after the discussion: 8%).

4. Discussion

4.1. Participatory Mapping Approach

Participatory mapping approaches refer to a range of methodologies to capture spatially explicit data in a participatory way [41]. In the current study, we conducted very basic stakeholder-based participatory mapping in order to test its suitability for selection of internal mitigation measures for inner coastal waters in Germany, Poland, and Lithuania (Figure 1). The results showed that the participatory mapping approach that was conducted could be a cost-saving and easy tool to identify sites preferred by local stakeholders for possible internal mitigation measures. It could also provide information on what kinds of internal mitigation measures were desired by local stakeholders, and it could further help to identify potential conflict zones. Damastuti and de Groot [42] described participatory mapping as a tool for co-producing knowledge with local stakeholders, often in contrast to the mechanistic approaches of traditional Geographic Information Systems (GIS) analysis, which avoids social complexity and political negotiation. Therefore, this approach offers the advantage that local stakeholder knowledge and opinions are directly implemented within the decision-making and implementation process of new internal mitigation measures within the WFD.

Considering the findings from the participatory mapping, several stakeholders saw the need for sea-based mitigation measures (Table 4). The results indicate that most stakeholders were aware that supporting internal measures was very well required to support the recovery process of coastal waters, as already proposed by Duarte et al. [9]. However, the results also show that the individual approaches were perceived differently according to the stakeholders' backgrounds as well as nationalities. When distinguishing between the individual workshops, it became apparent that the highest acceptance of EE measures was seen by German stakeholders, mostly including local governmental, non-governmental, and business representatives. However, if the stakeholder group consisted mainly of experts (scientists), EE and HE applications were favored in equal parts. Both stakeholder groups, however, avoided GE measures. Under GE measures, the most common method is the application of aluminum (Al) to remove phosphorus from the water column through precipitation and permanent burial [43]. While phosphorus precipitation by Al has already been successfully practiced in small lakes [44], there are significant knowledge gaps with regard to the brackish waters of the Baltic Sea [45,46]. In contrast to the results of the previous two workshops, it was surprising during the workshop in Klaipeda that the GE measures in particular were pinned, with a share of 33%.

Another aspect which became obvious was that even though the EE measures were pinned the most during all three workshops, the mussel mitigation approach was always pinned less compared with the measures involving macrophytes (Table 4). This was especially true for the workshop in Athens, Greece and Klaipeda, Lithuania. Within the Szczecin Lagoon (Poland) as well as in the Curonian Lagoon, mussel cultivation as a mitigation measure was only pinned once (Figure 4). Here, several assumptions are possible. On the one hand, it may be that mussel cultivation is generally viewed critically [47] as a measure for shallow inner coastal waters or because only the zebra mussel (*Dreissena Polymorpha*) and not the blue mussel (*Mytilus* spp.) can be cultivated in these waters.

In comparison with Poland and Lithuania, the stakeholders in Germany seemed to show a higher acceptance toward EE mitigation. However, it also has to be noticed that a share of the stakeholders in Germany preferred no measures at all.

The heterogeneous mapping results also show that this simplified approach alone was not sufficient enough to select and introduce internal mitigation measures in a targeted manner which could support the implementation of the WFD.

4.2. Expert- and Stakeholder-Based ESA Approach

Several studies have already shown that ecosystem service assessments can support stakeholder communication and policy implementation [29,30]. In our case, it can serve as a tool to visualize potential benefits and trade-offs and analyze patterns and processes at a regional level [25,42,48].

Our results have shown that, based on the stakeholder background, different assessment strategies can be beneficial. In the case of the expert-based assessment, the web-based assessment with the option to visualize the results in real time enabled new discussion strategies and could accelerate the duration of the assessment compared with the basic paper-based assessment. This was very well demonstrated when comparing the results from the conducted ESA in Denmark and Lithuania. The experts in Denmark, who were already familiar with the topic of mussel cultivation, still showed higher deviations for the impacts of a commercial mussel farm scenario compared with a quite similar IMTA scenario (Table 6), whereas the experts in Lithuania, consisting of scientists with a general background in marine science, showed only a little deviation, comparing the effects of two very contrasting scenarios (Table 7). Here, the chosen discussion strategy, which was to conduct the discussion after the assessment, seemed to not be beneficial.

Both expert groups agreed that a mussel farm which could run on a commercial level could benefit the selected provisioning, regulating, and cultural ESs around the mussel farm. Both groups mostly agreed on whether the scenario described would lead to an improvement or deterioration of the ES being assessed (Table 5). However, the degree of change differed in most cases. Some exceptions were the ESs “Oxygen provisioning” and “Burial of nutrients and organic matter”, which mirrors the general risks of mussel cultivation [21,49]. In both cases, the experts in Lithuania assessed a decline in the ESs, while the experts in Denmark determined a positive change. The differences in ratings can be attributed to a possible different understanding rather than that the scenarios were assessed in different systems (Skive Fjord, Denmark and Curonian Lagoon, Lithuania). Both systems are shallow and eutrophic [25,50]. While the experts in Lithuania possibly saw the overall threat of bio deposition and increasing dissolved nutrients [21,49], the experts in Denmark saw the benefits for the environment if a mussel mitigation farm acted as a nutrient sink [49,50].

While an ESA is appropriate for expert consultations, it does not seem to be usable for non-experts (e.g., local actors (governmental, non-governmental, or business actors)), since the number and description of ESs are too specific, and it would be too time-consuming to carry out [25]. Therefore, we tested a slimmed down version with reduced services (Table 8). Striking was that the results showed that the stakeholders rated the simplified ES “Nutrient regulation” equally for the beach mussel farm and the floating wetlands (Table 8). Here, the perception of the nutrient regulation capacity could be biased based on the scenario provided to the stakeholders. A floating macrophyte island of 1 ha would theoretically be able to remove a similar amount of phosphorus and nitrogen compared to a mussel farm of the same size. However, floating islands could never realistically be that large due to the negative shading effect on submerged vegetation. More than their impact on nutrient regulation, the stakeholders appreciated their potential role as biodiversity hotspots and a habitat for birds, insects, and aquatic fauna [51,52]. Those aspects seem more promising than their use purely for nutrient removal in eutrophicated waters, where the size limits the efficiency. This was also a debated topic during the discussions after the assessments.

A common disadvantage of the ESA is that the stakeholders have to evaluate prefabricated scenarios whose location is already determined. Preparing scenarios at a predefined location has the advantage that the scenario can be tailored to the location, but it lacks the possibility of including valuable experiences and perspectives from local stakeholders. Another potential weakness of this method might be that it requires a sufficient and diverse number of coastal stakeholders. If the number of coastal stakeholders is not sufficient or diverse enough, the decision-making process can be biased and result in lacking public acceptance after all. In order to have high participation of local stakeholders during

the implementation process of new measures, a web-based, simplified ESA would be most beneficial. Its shorter duration and the anonymous voting system help to ensure effective participation.

4.3. Implementation of Different Assessment Approaches into the WFD

While former studies gave first insights into the potential usage of ESA for the implementation of water quality improvement measures and their use within the integrated coastal management processes [25,39,48], they lacked concrete information about the application within the WFD implementation cycle itself. Based on our results and the experience we created, we see the following possible applications of ESA and PM in the selection and implementation of possible measures as exemplary for the German WFD implementation cycle (Figure 5).

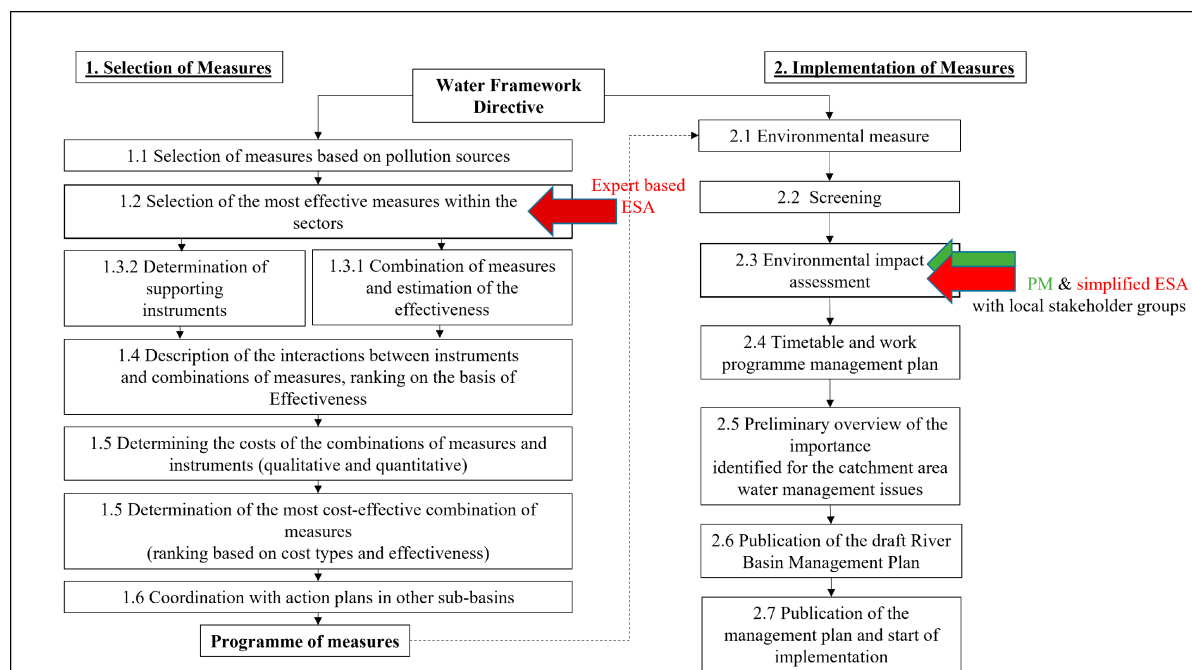


Figure 5. Flow chart of the planning and implementation process of the WFD in Germany and indication where ESA and a combination of PA and ESA could be beneficial to accelerating the selection and implementation of new mitigation measures.

Depending on the different pathways, the selection of measures (1), or the implementation of measures (2) (Figure 5), we propose different assessment approaches. During the selection of measures, we suggest an expert-based ESA. In Germany, the selection of measures is organized on a federal level. Therefore, experts which have a profound understanding of the concerned aquatic systems and the potential effects of the measures are needed. The position is different when it comes to the implementation of sea-based measures and the participation of governmental, non-governmental, industry, or other local stakeholders. During the screening process, a stakeholder-based PM approach could be used to identify potential application and conflict areas, as well as the general acceptance of different potential sea-based measures. In this context, the simplified ESA could help to identify a stakeholder's perception of sea-based measures and to identify misunderstandings. Furthermore, the holistic view on this measure can also visualize other advantages aside from nutrient reduction (e.g., benefits for biodiversity or economic benefits).

Public participation is not only a key element and a major challenge in the implementation of WFD in coastal waters but also in the other target water resources of the WFD [53]. Graversgard et al. 2017 [54], for example, showed that the engagement of local stakeholders during the planning of a river basin management plan resulted in better river

basin management plan than without local stakeholders. Therefore, an adapted ESA as well as a PM can potentially be beneficial for the implementation and planning process for the other water resources targeted by the WFD.

5. Conclusions

Our study has shown that stakeholders' views on sea-based mitigation measures differed based on their professional backgrounds or nationalities. In regard to EE measures, a comparison between different mussel mitigation scenarios showed that overall, the experts rated the effects of mussel mitigation on the selected ES positively. However, non-expert stakeholders seemed to prefer floating wetlands compared with a more effective mussel mitigation scenario. We have shown that an ESA designed for expert as well as for non-expert stakeholders and a PM approach can be valuable tools at different stages during the realization of the WFD. The tools can help to support the decision-making process during the selection of potential sea-based mitigation measures for the Program of Measures as well as during the implementation process. Especially during the implementation of measures, where stakeholder involvement is demanded, a combination of both approaches can be beneficial for revealing and clarifying spatial conflicts, stakeholder perceptions, as well as potential misinformation. A web-based approach can help enable new discussion strategies which can accelerate the duration of the assessment.

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