Economic and social analyses

Thematic assessment 2016–2021



Baltic Marine Environment Protection Commission



Economic and social analyses



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What is HELCOM?

Preface



problems transcend political, legal and other anthropogenic boundaries, and thus cannot be adequately solved by individual countries alone. Regional Seas Conventions (RSCs) such as the Convention on the Protection of the Marine Environment of the Baltic Sea Area establish legal frameworks for necessary transpoundary cooperation.

The Helsinki Commission (HELCOM) is an intergovernmental body composed of the Baltic Sea coastal states and the EU, and functions as the governing body of the Convention on the Protection of the Marine Environment of the Baltic Sea Area. HELCOM functions as a regional platform for cooperation with a broad spatial and sectoral reach, working with biodiversity and protection, shipping, fisheries management, maritime spatial planning (MSP), pressures from land and sea-based activities and regional governance. Furthermore, HELCOM has a wide vertical and horizontal scope, with established structures for transboundary cooperation within and across levels of organization, ranging across technical experts, authorities, managers and national ministries. HELCOM is also an established provider of infrastructure to support both regional and national work, including functioning as the natural regional data hub and tool developer as well as providing concrete support for regional assessments, ensuring that regional coherence and an ecologically valid perspective is maintained.

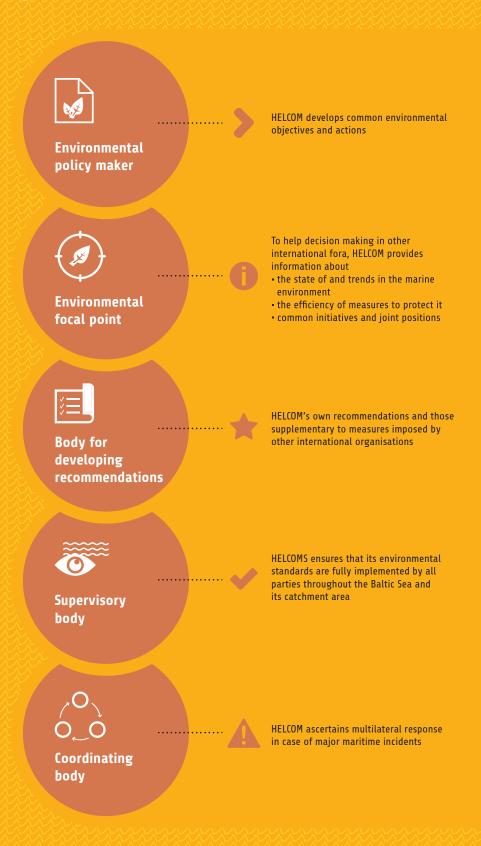
Benefits of cooperation at the regional level

- Benefitting from the expertise of others;
- Sharing of knowledge, information and resources:
- Improved effectiveness of measures due to regional coherence and mutually enforcing or synergistic actions;
- Action is taken at the ecologically relevant scale, i.e. the scale at which the environmen functions





HELCOM is...



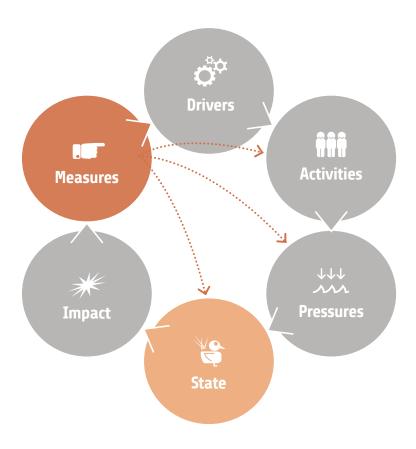


Figure P1 Conceptual overview of the management framework HELCOM works within.

Our activities at sea and on land cause pressures on the marine environment which in turn, to varying degrees, negatively impacts the ecosystem on which we all depend for our survival. These impacts cumulate and cascade through the ecosystem and eventually return to impact our wellbeing and that of society as a whole.

To limit the negative impact of our activities to within what the ecosystem can tolerate, we must understand what effects our actions have and then use that information to manage the activities which are causing negative impact. This is done through establishing well-founded and ecologically relevant targets and objectives to work towards and then taking concrete measures to ensure we reach them. Figure P1 shows the conceptual management framework HELCOM works within, and within which the holistic assessment is made. This is a regional version of the more common Driver-Activites-Pressures-Impacts-Response (DAPSIR) framework, which has been modified to fit the work under HELCOM.

Measures to improve the Baltic Sea environment are undertaken by many actors and at many levels, jointly at the global level, regionally at Baltic Sea level through HELCOM, by countries at national, county and local levels, and by initiatives in the private and public sector. The measures also differ in type, including technical improvements to minimise impact, economic and legislative measures, and measures directed towards raising awareness and incentives for changes in behaviour. In the Baltic Sea, where the transboundary aspects of environmental problems are highly evident, HELCOM plays a central role in coordi-

nating the management objectives and their implementation in line with the Helsinki Convention.

In order to allow the tracking, and to get a comprehensive and accurate overview of progress towards set objectives and targets, as well as to see if our measures are working and sufficient, assessments need to be conducted. In order to better understand the ecosystem and our relationship with it, and to ultimately improve the environmental status of the sea, we need to map activities which affect the marine environment, analyse what effects these activities have and how strong these effects are, and assess what this means for the ecosystem.

When using assessment to track progress of measures and management, and identify possible gaps or barriers, this needs to be done in two ways. On the one hand, we need to assess the level of implementation of the agreed measures, i.e. has the agreed action actually been taken and to what degree. This tells us about possible implementation gaps and can help to identify unforeseen barriers or challenges that need to be addressed. In HELCOM this is achieved through regular reporting and the use of the HELCOM Explorer tool. On the other hand, we need to understand and track the actual effects that the implemented measures have on the marine environment. This helps us understand if the measures which have been put in place are sufficient to limit the negative impact of our activities. Where the measures turn out to not be sufficient, the knowledge we gain from the assessments enables us to identify new or improved measures, which can be more targeted, resource efficient and/or adaptive.



Figure P2. The structure and process of the HELCOM holistic assessment. Within the assessment structure, highly detailed results are progressively aggregated, allowing anyone to explore the results at whatever scale is most relevant to them and culminating in the overall summary report on the State of the Baltic Sea.

Assessments also help us understand what pressures and measures need to be addressed at what level. Our activities cause various types of pressures, the impact of which can vary spatially and temporally. However, because of how dynamic the marine environment is, the majority of pressures in the marine environment have transboundary impacts. For measures and management to be effective it therefore has to be implemented at an appropriate level and this often means that implementation need to be regional, i.e. the scale at which they need to be addressed in order to be effective goes beyond the national borders of one specific country.

HOLAS

The Holistic Assessment of the Status of the Baltic Sea (HOLAS) is a reoccurring, transboundary, cross-sectoral assessment which looks at the effect of our activities and measures on the status of the environment. The assessment is a product of HELCOM. The HOLAS assessment covers, or approaches, the main themes to be considered when taking an ecosystem approach to management and provides regular updates on the environmental situation in the Baltic Sea. Each report captures a 'moment' in the dynamic life history of the Baltic Sea. The report highlights a broad range of aspects under the overarching themes of the state of the ecosystem, environmental pressures and human well-being and contributes to a vast sharing and development of knowledge both within and across topics. The focus of the assessment is to show results of relevance at the regional scale and large-scale patterns across and between geographic areas in the Baltic Sea. Each assessment provides a clearer picture of where we are, how things are connected, and what needs to be done.

The holistic assessment also specifically enables tracking progress towards the implementation of the 2021 Baltic Sea Action Plan (HELCOM 2021) goals and objectives and functions as a regional

contribution to the reporting under the Marine Strategy Framework Directive (MSFD) for those HELCOM Contracting Parties that are also EU Member States. The results of the assessment underpin HELCOM policy and the information from the assessment is incorporated in the ecosystem-based management of the Baltic Sea, as well as guiding measures nationally, regionally and globally.

The HELCOM holistic assessment is a multi-layered product (Figure P2). Within the assessment structure, highly detailed results are progressively aggregated, allowing anyone to explore the results at whatever scale is most relevant to them and culminating in the overall summary report on the State of the Baltic Sea.

Data

The collection, reporting and collation of national monitoring data at the Baltic Sea level forms the basis of the assessment. The data is spatially presented using a defined assessment unit system dividing the Baltic Sea into assessment units representing different levels of detail, in a regionally agreed nested system. The data then feed into regionally agreed evaluation and assessment methods. This allows us to explore trends over time, spatial aspects, as well as results, in order to indicate potential future developments and geographic areas of key importance for the assessed themes.

Indicators

HELCOM core indicators have been developed to assess the status of selected elements of biodiversity and human-induced pressures on the Baltic Sea and thus support measuring the progress towards regionally agreed targets and objectives. The core indicators are selected according to a set of principles including ecological and policy relevance, measurability with monitoring data and linkage to anthropogenic pressures (HELCOM 2020a). The observed status of HELCOM indicators is measured in relation to a regionally agreed threshold value specific to each indicator, and in many cases at the level of individual areas in the Baltic Sea. The



majority of the indicators are evaluated using data from regionally coordinated monitoring under the auspice of HELCOM and reported by the Contracting Parties to the Convention. The status of an indicator is expressed as failing or achieving the threshold value. Hence, the results indicate whether status is good or not according to each of the core indicators. HELCOM core indicators make up the most detailed level of results, presented in the dedicated indicator reports (https://indicators.helcom.fi).

Thematic assessments

A basic criterion for HELCOM core indicators is that they are quantitative and that their underlying monitoring data and evaluation approaches are comparable across the Baltic Sea. This is to ensure that they are suited for integrated assessment. Integrated assessments are assessments where the quantitative information from indicator evaluations or other data, as well as qualitative information, is combined by topic, to produce a broader, more holistic overview of the situation for that specific topic and, subsequently, for the theme under which that topic is included. The integrated assessments are made using the BEAT (biodiversity), HEAT (eutrophication) and CHASE (hazardous substances) assessment tools, as well as the Spatial Pressures and Impacts Assessment tool, developed for this purpose by HELCOM. In addition to presenting whether status is good or not, the integrated assessment results also indicate the distance to good status. Distance to good status is shown by the use of five assessment result categories; out of which two represent different levels of good status and three different levels of not good status.

Quantitative integrated results can then be further combined with qualitative assessment results (where quantifiable information is not available) and contextual information to form five thematic assessments, each with their own report (Biodiversity, Eutrophication, Hazardous substances, marine litter, underwater noise and non-indigenous species, Spatial distribution of pressures and impacts as well as Social and economic analyses). This report represents a thematic assessment and covers the theme economic and social analyses.

The overall aim of a thematic assessment is to present what the results of the various assessments related to the theme of economic and social analyses are, how they have been produced as well as their rationale, all within the relevant policy and scientific frameworks. Confidence in the assessments is presented together with the results to ensure transparency and facilitate their use. The thematic assessment reports are an integral part of the overall Status of the Baltic Sea assessment but also function as stand-alone reports. The reports are more technical in nature than the summary report, as they are intended to give details to the assessments, explaining underlying data and indicators to the extent that is needed to ensure that the HOLAS 3 assessment is transparent and repeatable.

Summary report

The main aim, and the added value, of the Summary Report lies in the possibility to link the information from the topical and thematic assessments together and thus highlight the holistic aspects of the assessment for each topic. With this in mind the Summary Report focuses on presenting the results and looking more in depth at why we are seeing these results, i.e., presenting the results of the thematic assessments by topic but linking and combining these topical results with the information and input from the other assessments/sources to provide context and analysis.



Summary

The Baltic Sea countries benefit considerably from their utilization of the Baltic Sea, both economically and socially. These benefits include jobs, income, natural resources, and various other contributions to personal well-being. For example, fish for nutrition from wild capture fisheries and aquaculture are worth 163 million euros in gross value-added to Baltic Sea economies and offshore wind turbines generate 9.2 terawatt hours of electricity worth an estimated 878 million euros per year.

However, the ways in which the sea is used also causes environmental degradation with its own costs to human well-being. For example, reach-

costs to human well-being. For example, reaching good environmental status in national marine waters by 2040 is collectively estimated to be worth 5.6 billion euros per year to the region's population. Additionally, degraded environmental conditions are estimated to cost the region's population 9 billion euros annually in terms of forgone recreational benefits.

Ecosystem services and ecosystem accounting are two promising frameworks for balancing these somewhat conflicting perspectives. While ecosystem accounting still requires development to be used at the Baltic Sea scale, ecosystem services assessments can be used to better understand the socio-economic values related to the Baltic Sea environment right now. Nutrient sequestration alone has an estimated worth of nearly 10.5 billion euros per year in saved costs. The estimated worth of

nutrition benefits from wild caught fish and aquaculture are between 1.4 and 3.6 billion euros per year and benefits from cultural ecosystem services like recreation and other interactions with the marine environment are estimated at 33.7 billion euros per year. Further, the estimated monetary benefits of carbon sequestration in the Baltic Sea region, which range from 622 to 1554 million \in on average per year, can help policy makers understand the economic benefits of investing in measures to enhance carbon sequestration in the region. These estimations can also contribute to the development of policies aimed at promoting the preservation and restoration of ecosystems that support carbon sequestration.

Socio-economic analyses provide information and perspectives to help inform public decision-making and gain a better understanding of how the environment and society are interconnected. There are no absolute answers to the topics that are explored in this thematic assessment, but rather, the goal is to provide relevant information to inform decision-making.

This work involves a continuous effort to improve the available data and methodologies. Additionally, two new assessments to HOLAS have been included in this report. Cost-benefit analyses are not a new tool, however, due to the scarcity of data, they have not been commonly used at the regional scale. As data availability issues are addressed, cost-benefit analyses can become an effective tool for the Baltic Sea. Additionally, a proof-of-concept analysis has been conducted to evaluate the societal and environmental factors that influence the activities, pressures, or the state of the marine environment. These drivers include consumer demand, technology adoption, and macroeconomic influences. Understanding these linkages better could help design more effective environmental measures in the future macroeconomics.

The economic and social analyses linked to the marine environment give a valuable perspective on the relationship between society and the environment. The management of the Baltic Sea is becoming increasingly influenced by economic and social factors, and their importance and relevance is only expected to grow in the coming years.

1. Introduction



Figure 1. Schematic showing what sections of the DAPSIM cycle this assessment focuses on.



1.1. General introduction to economic and social analyses in the Baltic Sea

The relationship between humanity and nature is a multifaceted and nuanced one. On the one hand, our well-being and prosperity depend on a healthy and thriving environment that supports our health, economies, and overall quality of life. At the same time, we also derive benefits from human activities that may have negative impacts on the environment. This creates a dynamic tension between the desire to preserve the natural world and the need to use it for our own benefit. One way to navigate this tension is through the use of economic and social analysis. This approach takes into account the environmental and societal impacts and values of various courses of action, providing a transparent and sound framework for decision making that balances the needs of both the environment and society. With this approach, we can chart a course towards a more sustainable and effective future for both nature and humanity.

Economic and social analysis plays a crucial role in the practical implementation of environmental protection and management policies related to the marine environment. For instance, the EU's Marine Strategy Framework Directive (2008/56/EC) requires Member States to carry out an economic and social analysis of the use

of marine waters and cost of degradation analyses and to consider social and economic impacts of planned measures for protecting the marine environment (EU 2008). At the sea region level, the HELCOM Baltic Sea Action Plan (HELCOM 2021) includes eight actions targeted toward improving the quality and integration of economic and social analyses in decision-making (Table 1). Nearly all EU environmental directives require accounting for economic, social, and cultural aspects, and a broad objective of the UN Sustainable Development Goals is the improvement of economic and social equity. The use of economic and social analysis tools is therefore crucial for making informed decisions that protect and sustainably use the marine environment, in order to secure the benefits for both society and environment.



1.2. Overview of the thematic assessment report

The thematic assessment of social and economic analyses covers five types of analyses and includes an introductory overview and conclusions chapters.

With HOLAS 3, HELCOM has significantly expanded the scope of its analysis to include a range of economic and social issues, reflected in the variety of approaches included in the report. The report includes results for two well established regional analyses (Economic and social analysis of the use of marine waters, and Cost of degradation), analyses that are just now expanding to the regional level at HELCOM (Assessment of ecosystem services and Drivers indicator assessments), and one review of the state of the art of an analysis that hasn't yet been integrated into HELCOM work (Cost-benefit analysis).

Each chapter is structured similarly, with a brief summary of key information, an overview of the analysis, results, a discussion of how the analysis fits into the HELCOM DAPSIM framework, a simplified methodology, and suggestions for improving the analysis in the future. Expanded methodologies for the analyses can be found in Annex 1, when relevant. Each chapter addresses relevant aspects of the relationship between the human

and the environmental dimensions. While the assessments are complementary, they do not currently form a single joint conclusion. Instead, they should be seen as tools for exploring the relationship between preserving and exploiting the Baltic Sea environment from various perspectives.

Confidence is reported in a systematic way throughout the report based on the quality of the input data (Table 2).

To get an overview of the report and its contents, start with Chapter 2: Overview of the Economic and Social Analyses Assessment Approach. This chapter provides a bird's eye view of the thematic assessment, including what is covered and where to find it. The report can be read in any order, so feel free to follow your interests and read the chapters in the order that interests you most.

Table 1. Outline of for what 2021 BSAP segment and actions this topic is relevant.

Code Action						
Horizo	Horizontal topics: Economic and social analyses					
HT15	By 2023, integrate economic and social analyses in HELCOM work strands to support the implementation of the ecosystem-based approach and allow for assessment of the linkages between the marine environment and human wellbeing, including carrying out regionally coordinated economic and social analysis of the marine environment.					
HT16	By 2028, improve the use of results from economic and social analyses in decision-making, including through establishing a set of indicators that describe the economic and social aspects of the marine environment.					
HT17	By 2030, integrate quantitative and qualitative economic values of the environment into the management of human activities and maritime spatial planning.					
HT18	By 2023, identify potential uses of ecosystem services assessment and valuation, further develop and apply regionally coordinated methods in support of analyses of ecosystem services and provide an initial demonstration of how they can be used in policy development.					
HT19	By 2028, apply the framework of ecosystem accounting to assess the contributions of marine ecosystems to economic activity (e.g. Gross domestic product (GDP)) using values that are compatible with the system of national accounts and comparable with other economic sectors.					
HT20	By 2024 analyse existing tools for analysing sufficiency of measures, with the aim to plan monitoring and assessment of the effect and cost of measures, in order to further make use of the experiences when the need for new measures occurs. By 2028, further develop and apply regionally coordinated methods for analyses of sufficiency of measures as well as for cost-effectiveness of measures and costs and benefits to achieve good environmental status of the Baltic Sea marine environment.					
HT21	By 2025 identify incentives to reduce pressures on the marine environment, including public and private economic and regulatory incentives, and by 2030 increase the use of incentives and fill possible gaps.					
HT22	By 2025 HELCOM should identify subsidies or incentives which are harmful for the marine environment and, by 2030 work, in cooperation with relevant international organizations, on phasing out such subsidies or incentives.					

Table 2. Applied categories for assessing confidence in the socioeconomic estimates.

Low confidence	There are many factors creating variability in the estimated subject, no sufficient empirical data to estimate this variability; estimate is based on scarce data, heavily relying on extrapolations and assumptions
Moderate confidence	The estimate is based on some empirical data, but involves large extrapolations and/or assumptions
Good confidence	The estimated is based on sufficient empirical data, with only minor extrapolations and/or assumptions
High confidence	The estimated is based fully on empirical recent data, practically no extrapolations or assumptions

2. Overview of the economic and social analyses assessment approach

The regional capacity for economic and social analyses has expanded considerably during the HOLAS 3 assessment period, which can be seen in the numerous advances in this assessment, compared to HOLAS 2 (HELCOM 2018). The use of marine waters analysis has been updated and expanded to cover additional human activities (Chapter 3). The cost of degradation analysis has been updated using the most current scientific literature (Chapter 4). In addition, great advances have been made for analyses not previously included in HOLAS. A spa-

tially explicit analysis of regional ecosystem service supply and well-being impacts has been developed for a range of relevant marine ecosystem services (Chapter 5). The report also includes a review of the state of the art and uses of cost-benefit analyses, including an evaluation of obstacles to their use at the regional scale (Chapter 6). Finally, the report includes an analysis of drivers potentially impacting the state of the Baltic Sea environment, representing the first efforts to develop driver indicators in HELCOM (Chapter 7).

Table 3. Overview of data components included in the different topics for economic and social analyses presented in this thematic assessment report.

	Торіс	Sector/Subject	Metric	
		Fish and shellfish harvesting	Value of landings (€)	
	aters		Gross value added (€)	
	oo autine Aquaculture		Number of persons employed (full-time equivalent (FTE))	
Chapter 3		Value of production (€)		
			Gross value added (€)	
	Usc		Number of persons employed (FTE)	

Data for the economic and social analyses assessment are primarily from official statistics released by the Contracting Parties and scientific literature (Table 3). The scope for carrying out analyses at this stage is partially restricted by that data collation from these sources is not necessarily coordinated or coherent across HELCOM countries in the way that is seen for several types of environmental monitoring and ecological data. Updates to reporting standardization requirements within the EU are very important to ensure availability of relevant statistics from EU member states. Coordinating relevant scientific research and the calendars for assessments in HELCOM and in relation to the Marine Strategy Framework Directive would improve the assessments dependent on environmental valuation studies, such as the cost of degradation, which has limited data currently.

Table 3. (Continued). Overview of data components included in the different topics for economic and social analyses presented in this thematic assessment report.

	Торіс	Sector/Subject	Metric
		Tourism and leisure	Number of nights spent at tourist accommodation establishments in coastal areas
			Value added at factor cost from coastal tourism accommodation sector (€)
			Number of persons employed (FTE) in coastal tourism accommodation
			Total societal benefits (measured by consumer surplus) received from Baltic Sea recreation (€)
		Marine transport infrastructure	Gross weight of goods handled in all ports (tons)
	Iters		Passengers embarked and disembarked in all ports
173	e wa	Shipping	Number of persons employed (FTE) in marine freight transport
Chapter	arin		Value added at factor cost from marine freight transport (€)
_단	ofma		Number of persons employed (FTE) in marine passenger transport
	Value added at factor cost from marine passenger transport (€)		
		Renewable energy generation	Installed offshore wind power capacity (MW)
			Estimated wholesale value of electricity generated by offshore wind (€)
		Extraction of minerals	Weight of extracted marine aggregates (tonnes)
		Waste treatment and disposal	Benefits to society (measured by avoided costs) from nitrogen disposal in the Baltic Sea (€)
			Benefits to society (measured by avoided costs) from phosphorus disposal in the Baltic Sea (€)

Table 3. (Continued). Overview of data components included in the different topics for economic and social analyses presented in this thematic assessment report.

	Topic	Sector/Subject	Metric
4	dation	Well-being impacts from achieving GES for all descriptors by 2040	Willingness to pay for achieving GES state (€/per person/year) and total benefits to society (€/year)
Chapter	Cost of degradation	Change in the recreational benefits to society from improved state of the marine environment	Changes in the recreational benefits (consumer surplus) comparing two environmental scenarios (€/per person/year and total €/year)
		Regulating ecosystem services	Carbon sequestration in eelgrass habitats (tonnes/year)
			Well-being impacts from carbon sequestration by eelgrass habitats (€/year)
			Carbon sequestration in soft-bottom sediments (tonnes/year)
			Well-being impacts from carbon sequestration in soft-bottom sediments (€/year)
			Carbon assimilation by eelgrass (tonnes/year)
			Carbon assimilation by <i>Fucus spp.</i> (tonnes/year)
			Carbon storage by eelgrass (tonnes)
	es S		Carbon storage by <i>Fucus spp.</i> (tonnes)
r5	ervi		Nitrogen sequestration in eelgrass habitats (tonnes/year)
Chapter!	em s		Well-being impacts from nitrogen sequestration by eelgrass habitats (€/year)
ర్	Ecosystem services		Nitrogen sequestration in soft-bottom sediments (tonnes/year)
	S		Well-being impacts from nitrogen sequestration in soft-bottom sediments (€/year)
			Nitrogen assimilation by eelgrass (tonnes/year)
			Nitrogen assimilation by Fucus spp. (tonnes/year)
			Nitrogen storage by eelgrass (tonnes)
			Nitrogen storage by Fucus spp. (tonnes)
			Phosphorus sequestration in eelgrass habitats (tonnes/year)
			Well-being impacts from phosphorus sequestration by eelgrass habitats (€/year)
			Phosphorus sequestration in soft-bottom sediments (tonnes/year)

Table 3. (Continued). Overview of data components included in the different topics for economic and social analyses presented in this thematic assessment report.

	Topic	Sector/Subject	Metric
			Well-being impacts from phosphorus sequestration in soft-bottom sediments (€/year)
			Phosphorus assimilation by eelgrass (tonnes/year)
			Phosphorus assimilation by Fucus spp. (tonnes/year)
			Phosphorus storage by eelgrass (tonnes)
			Phosphorus storage by <i>Fucus spp.</i> (tonnes)
		Provisioning ecosystem services	Catch (tonnes/year) for relevant fish species (herring, sprat, cod, flounder)
			Monetary (market) value of the sea fish catch (€/year) for relevant species (herring, sprat, cod, flounder), estimated based on market prices of fish products
	vices		Marine aquaculture production (tonnes/year) for relevant species
Chapter 5	Ecosystem services		Monetary (market) value of the marine aquaculture production (ϵ /year), estimated based on market prices of aquaculture products
ਹ	Ecosy	Cultural ecosystem services	Illustration: Spatial assessment of suitability of coastlines for practising various recreational activities.
			Illustration: Relative importance of the marine environmental characteristics for deriving benefits from cultural ecosystem services.
			Societal benefits (measured by consumer surplus) of cultural ecosystem services related to recreation in the Baltic Sea (ϵ /year).
			Illustration: Relative importance of benefits from individual cultural ecosystem services according to citizens' preferences.
		All ecosystem services	Illustration: Benefiting population for relevant marine ecosystem services (% share of the total national population).
			Illustration: Relative importance of benefits from all relevant marine ecosystem services according to citizens' preferences.
Chapter 6	Cost-benefit analysis	Review of cost-benefit analyses and the state-of-the-art for regional scale CBAs	

Table 3. (Continued). Overview of data components included in the different topics for economic and social analyses presented in this thematic assessment report.

	Торіс	Sector/Subject	Metric
		Demographics	Descriptive
		Consumer demand	
		Globalization	
		Subsidies	
	rs	Regulations	
	Drivers	Macroeconomic conditions	
		Technology adoption	
2		Investment	
oter		Political will	
Chapter		Socio-economic setting	
		International relations	
		Nutrient input from agriculture	Agricultural nitrogen balance (kilograms/hectare)
	ors		Agricultural phosphorus balance (kilograms/hectare)
	Driver indicators	Nutrient input from urban and industrial sources	Population connected to tertiary wastewater treatment plants (%, count)
	ind	Commercial fishing	Total excess TAC by weight (%)
	rive		Number of TACs above ICES advice
	Δ		Gross value of landings per full-time equivalent employee
			Weight of landings and full-time equivalent employees



3. Results for the economic and social analysis of the use of marine waters



Assessment results in short

- The Baltic Sea countries receive significant economic and social benefits from the use of the Baltic Sea. These benefits include jobs, income, natural resources, and various other contributions to personal well-being. While many of these activities can result in degradation of the environment, they are also critical to human well-being.
- Measures for the protection and management of the marine environment have impacts in terms of environmental benefits, but also potential economic or societal costs and benefits. The use of marine waters analysis provides insight into the socio-economic values currently obtained from the Baltic Sea to inform these discussions.



3.1. Introduction to the economic and social analysis of the use of marine waters

The Baltic Sea countries derive benefits from human activities that utilize or depend on the Baltic Sea in various ways. The way any particular human activity utilizes the Baltic environment will differ, these activities can involve the use of tangible resources (sand mining), space (shipping and off-shore wind power), or intangible resources (such as recreation and tourism). Some activities are dependent on the state of the marine environment (fishing) while others are not (extraction of oil and gas) (Bryhn *et al.* 2020). The analysis aims to estimate the magnitude of the benefits generated for these activities, covering relevant socio-economic impacts, such as revenues for economic activities and employment.

This analysis highlights the current socio-economic values that the Baltic Sea states receive from the Baltic Sea. It identifies relevant activities and recognizes the interactions between these activities and the marine environment in terms of the environmental impacts and dependence on the state of the marine environment. The so-

cio-economic values or the impacts of the sea use are assessed by analysing common socio-economic indicators, which provide an approach that captures complex socio-economic processes in single numbers. The used indicators characterise the main socio-economic impacts of use of the sea. Since diverse indicators and data are used, the goal of this section is not to provide any kind of total benefit estimates but rather to illustrate the importance of marine environment for the economies of the Baltic Sea states. The assessment covers the main activities directly using the sea and benefiting from the sea use, providing estimates of a wide range of socio-economic benefits.

3.1.1 Socio-economic indicators

The presented indicators were selected based on availability of data across multiple countries and with the goal of capturing both economic and social dependence on the use of the marine environment. As indicators, value added shows the contribution of the sector to the national economy from a macro-economic perspective, while the employment indicators relate to the social impacts of

the use of marine environment. Non-market values for marine and coastal recreation are also included to cover relevant well-being impacts. The data sources include Eurostat, industry associations, regional studies and national statistics.

- Value added is a measure of productivity which shows the contribution of the activity or sector to the national economy. Gross value added (GVA) is used when available. It shows the value of the goods and services that have been produced minus the cost of all inputs and raw materials that can directly be attributed to production. Eurostat uses the indicator value added at factor costs which is similar to GVA but also accounts for operating subsidies and indirect taxes (Eurostat 2022a; STECF 2021a).
- Employment is a proxy for a social indicator. When possible, the indicator full-time equivalent employment (FTE) is used to allow better comparison between activities. Full-time equivalent employment is the total hours worked in an activity divided by average annual hours worked in a full-time job in the relevant country. Alternatively, number of persons employed is the sum of number of employees receiving compensation for work and unpaid persons employed. This indicator captures the total number of involved individuals rather than the standardized number of jobs available as in the FTE indicator.
- Non-market valuation data are used in addition to the national statistics to assess the socio-economic benefits from marine and coastal recreation. The relevant indicator to measure the value of a trip is consumer surplus, which describes the benefits people obtain from recreation. Market prices or statistics of the tourism sector are insufficient for capturing the full socio-economic importance of the marine related recreation.
- When the above socio-economic indicators are not available, other indicators are used. For the fisheries sector value of landings and value of production are used in addition to GVA to characterize wider socioeconomic benefits from fish resources provided by the sea. The value of landings or production is calculated using the wholesale price and quantity data (STECF 2021b). These estimates do not capture the full consumer surplus at final sale. Avoided costs of nutrient treatment is used to estimate the societal benefits of nitrogen and phosphorus dis-

- posal in the Baltic Sea by human activities. Estimated wholesale value of electricity generated by offshore wind is an estimate of the income derived from electricity generation.
- When no socio-economic indicators are available, quantitative indicators of activity are used, for example, number and capacity of installed offshore wind power turbines or number of ports. Although they do not directly measure the economic significance, they can be converted into economic estimates using assumptions and conversion factors. The use of non-economic data also allows better characterisation of sectoral and activity trends over time (growth or decline of activity).



3.2. Details on the assessment results for the economic and social analysis of the use of marine waters

3.2.1 Fish and shellfish harvesting

The fish and shellfish harvesting sector depends on the quality of the environment to produce fish of a harvestable size which can then be sold for human consumption or other purpose. Fish and shellfish harvesting is a sector involved in the extraction of living resources (Table 4).

Confidence in these estimates is high. STECF has extensive experience in developing these estimates. However, not all the data originates from official national statistics and employment data is not available at the same spatial scale as landing data, requiring additional assumptions to generate Baltic Sea specific employment estimates (STECF 2021b). As a result some uncertainty remains in the estimates.

The total value of Baltic Sea landings declined then stabilized in 2014 at approximately 218-220 million € and declined again in 2018 to approximately 200-208 million € (Figure 2). Individual countries have stable or slightly declining total landing values. Sweden and Poland have extracted the largest catch values in recent years, with Sweden having the current largest at 47 million €. However, gross value added has not shown a similar decline (Figure 3). The region produced its highest GVA during 2018, boosted by 30% gains in Sweden.

Table 4. Socio-economic indicators related to fish and shellfish harvesting for the most recent data year (2019). Source: Scientific, Technical and Economic Committee for Fisheries (STECF) (2021b). All monetary values have been adjusted for inflation; constant prices (2015) using Eurostat (2022i). STECF does not report on Russia, as it is not an EU member state.

Country	Value of landings (million €)	Gross value added (million €)	Number of persons employed (FTE)	Confidence
Denmark	29.1	15.3	148	High
Estonia	13.8	8.1	326	High
Finland	35.3	17.4	258	High
Germany	12.7	5.2	540	High
Latvia	16.1	7.6	262	High
Lithuania	4.4	1.9	91	High
Poland	41.9	23.2	2157	High
Russia ^a	no data	no data	no data	
Sweden	47.1	43.3	286	High
Total	200.3	122.0	4068	Good

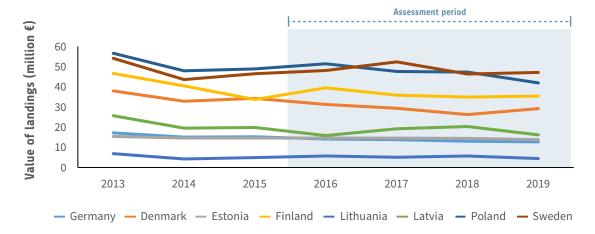


Figure 2. Value of landings (million €) 2013 – 2019.

Shading indicates years included in the HOLAS 3 assessment period. Source: STECF 2021b. All monetary values have been adjusted for inflation; constant prices (2015) using Eurostat (2022i). STECF does not report on Russia.

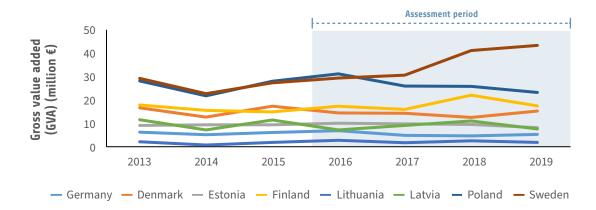


Figure 3. Gross value added (million €) 2013 – 2019.

Shading indicates years included in the HOLAS 3 assessment period. Source: STECF 2021b. All monetary values have been adjusted for inflation; constant prices (2015) using Eurostat (2022i). STECF does not report on Russia.

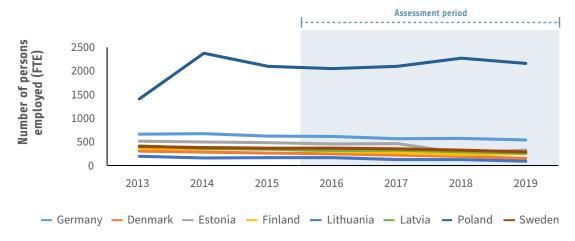


Figure 4. Number of persons employed (FTE) 2013 – 2019.
Shading indicates years included in the HOLAS 3 assessment period. Source: STECF 2021b. All monetary values have been adjusted for inflation; constant prices (2015) using Eurostat (2022i). STECF does not report on Russia.

Approximately 1000 full-time equivalent jobs have been lost from the sector since the peak in 2014 (Figure 4). However, more than 4000 FTE jobs remain, with Poland employing more than half of these.

3.2.2 Aquaculture

Marine aquaculture is a sector involved in the cultivation of living resources (fish and shellfish) in the marine environment. Aquaculture is less dependent on the quality of the environment than fish and shellfish harvesting, mostly utilizing space and clean water. The presented data includes both marine fish and shellfish aquaculture (Table 5). The sector currently produces a negligible number of freshwater crayfish which would be included in the shellfish aquaculture data; however, this may not be true in past or future data (STECF 2021a). German production is confidential due to the low number of participating firms. Estimates include both fish sold for food and as stock, however hatchery and nursery operations typically occur at inland facilities and would therefore not be included in the marine fish aquaculture data.

Almost all marine aquaculture in the region is conducted in Finland and Denmark (Table 5). Regional production is dominated by rainbow trout cultivation (90%+) with the remaining production consisting primarily of European white fish, Atlantic Salmon, and blue mussels (STECF 2021a).

Sales volume in the industry has shown significant growth over the past decade, almost doubling in size (Figure 5), while gross value added has increased almost 400% over the same period (Figure 6). Aquaculture now accounts for approximately 36% of the region's fish production by value, compared to 22% in 2013.

Sectoral employment grew significantly between 2012 and 2016 but has plateaued or slightly declined since the 2016 maximum (Figure 7). Finland and Denmark show very similar FTE and GVA, while Denmark has consistently produced a slightly higher sales value.

Confidence in these estimates is high, as STECF has extensive experience in developing these estimates. However, the entire data does not originate from official national statistics, therefore the estimates may still include some uncertainty.

Table 5. Socio-economic indicators related to aquaculture for the most recent data year (2018). SSource: STECF 2021a. All monetary values have been adjusted for inflation; constant prices (2015) using Eurostat (2022i). STECF does not report on Russia.

Country	Sales value (million €)	Gross value added (GVA) (million €)	Number of persons em- ployed (FTE)	Confidence
Denmark	72.8	20.8	117.0	High
Estonia	0	0	0	High
Finland	46.9	19.3	111.0	High
Germany	confidential	confidential	confidential	
Latvia	0	0	0	High
Lithuania	0	0	0	High
Poland	0	0	0	High
Russiaª	no data	no data	no data	
Sweden	0.6	0.8	21.34	High
Total	120.2	40.9	249.34	Good

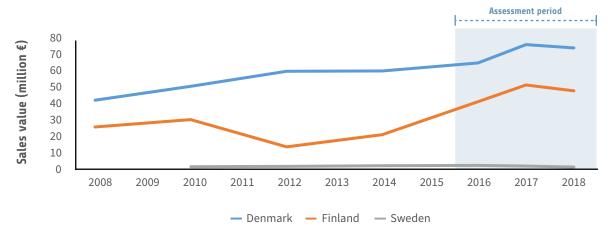


Figure 5. Value of landings (million €) 2013 – 2019.

Shading indicates years included in the HOLAS 3 assessment period. Source: STECF 2021a. All monetary values have been adjusted for inflation; constant prices (2015) using Eurostat (2022i). STECF does not report on Russia.

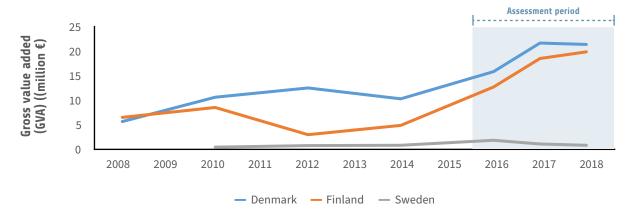


Figure 6. Gross value added (million €) 2013 – 2019.

Shading indicates years included in the HOLAS 3 assessment period. Source: STECF 2021a. All monetary values have been adjusted for inflation; constant prices (2015) using Eurostat (2022i). STECF does not report on Russia.

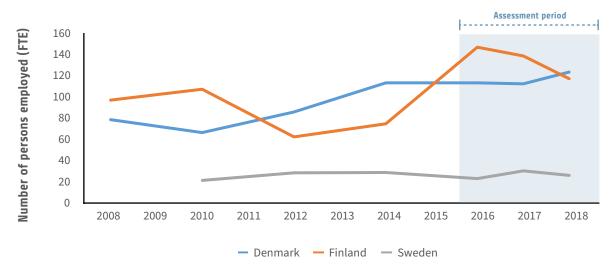


Figure 7. Number of persons employed (FTE) 2013 – 2019.
Shading indicates years included in the HOLAS 3 assessment period. Source: STECF 2021a.Tourism and leisure.

3.2.3 Tourism and leisure

Coastal and marine tourism includes a wide range of economic sectors including accommodation, food and drinks, and variety of other sectors serving goods and services for tourism and leisure activities. Moreover, it includes diverse leisure activities, such as boating, water sports, recreational fishing, nature watching and recreation on the beach. Most marine and coastal tourism and leisure activities are at least partly dependent on the quality of the marine environment, but the degree of dependence will widely vary.

It is difficult to separate tourism and leisure activities that are directly linked to the marine environment from those that are not. However, there are several methods for estimating the market and non-market benefits of this type of sea use activity.

National accounts approach

The national accounts approach is based on characterizing the socio-economic benefits in relation to tourism accommodation sector. Despite having the lowest share of nights spent at tourist accommodation in coastal areas, tourist accommodations in Germany represent about half of the total nights in Baltic Sea countries (Table 6). However, it should be noted that these statistics include data from the coastal areas of the North Sea for

Denmark, Germany, and Sweden. This may have a significant impact on the statistics for Denmark and Germany, as a larger proportion of nights spent at tourist accommodations in these countries may be in coastal areas of the North Sea. Over the past decade, there has been a general trend of growth in the number of nights spent at tourist accommodations in coastal areas for all of these countries, with an average increase of 35%. Some countries, such as Latvia, Lithuania, and Poland, have seen even more substantial growth in this area, with more than 50% increases. In terms of value added, the Baltic states have seen an average of 40% growth over the past decade, with Lithuanian value added more than doubling. Employment in the tourism industry in these countries has also grown, but at a more moderate pace of about 13% on average.

Confidence in these estimates is moderate. They are based on officially reported data gathered from Eurostat, which assumes a broad definition of coastal tourism (all accommodation activities in coastal areas) and only include a portion of total tourism spending. Finland and Latvia have provided alternative calculations, which exclude one or more large cities from this estimate. In addition, they include also the data in relation to the North Sea for Denmark, Germany and Sweden.

Table 6. Socio-economic indicators related to tourism and leisure for the most recent data year (2019).

Source: Eurostat 2022b, Eurostat 2022c, CSBL 2022, Visit Finland 2023. All monetary values have been adjusted for inflation; constant prices (2015) using Eurostat (2022i).

Eurostat does not report on Russia. Values according to the national assessment approach and data for 2019 for the marine-related tourism (excludes the capital city Riga).

Country	Share of the number of nights spent at tourist accommodation establishments in coastal areas (% of the total national number of nights)	Number of nights spent at tourist accommodation establishments in coastal areas (million nights)	Annual value added at factor cost from coastal tourism accommodation sector (million €)	Number of persons employed in coastal tourism accommodation (thousand FTE)	Confidence
Denmark	91%	31.3	907.2	12.7	Moderate
Estonia	78%	5.4	111.5	4.7	Moderate
Finland	40%	9.2	200.5	3.5	Moderate
Germany	19%	84.3	3302.7	76.6	Moderate
Latvia ^b	22%	4.6	85.0	4.4	Moderate
Lithuania	25%	2.2	37.2	1.8	Moderate
Poland	25%	23.1	451.3	15.5	Moderate
Russia	no data	no data	no data	no data	
Sweden	62%	39.5	1455.8	24.0	Moderate
Total	30%	199.6	6551.2	143.3	Moderate/Low

Nights spent at tourist accommodation establishments in coastal areas

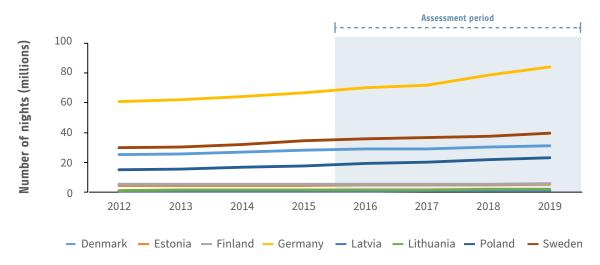


Figure 8. Number of nights spent at tourist accommodation establishments in coastal areas (million nights) 2012 – 2019. Shading indicates years included in the HOLAS 3 assessment period. Source: Eurostat 2022b, Eurostat 2022c, CSB of Latvia, TUV050. All monetary values have been adjusted for inflation; constant prices (2015) using Eurostat (2022i). Eurostat does not report on Russia.

Annual value added at factor cost from coastal tourism accommodation sector

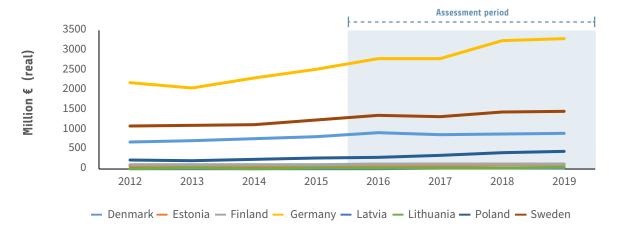


Figure 9. Value added at factor cost from coastal tourism accommodation sector (million €) 2012 – 2019.

Shading indicates years included in the HOLAS 3 assessment period. Source: Eurostat 2022b, Eurostat 2022c, CSB of Latvia, TUV050. All monetary values have been adjusted for inflation; constant prices (2015) using Eurostat (2022i). Eurostat does not report on Russia.

Number of persons employed in coastal tourism accommodation

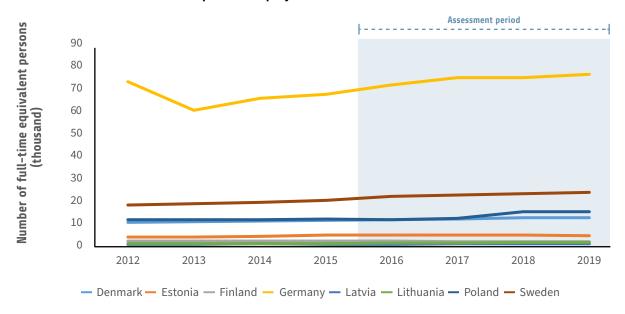


Figure 10. Number of persons employed (thousand FTE) in coastal tourism accommodation 2012 – 2019.

Shading indicates years included in the HOLAS 3 assessment period. Source: Eurostat 2022b, Eurostat 2022c, CSB of Latvia, TUV050. All monetary values have been adjusted for inflation; constant prices (2015) using Eurostat (2022i). Eurostat does not report on Russia.

Non-market approach

To account for the non-market benefits of coastal tourism and leisure in the Baltic Sea region, this assessment includes estimates of the benefits from leisure visits to the region. These estimates (Table 6) were derived from a travel cost study on recreational benefits of sea use in Finland, Germany and Latvia (Ahtiainen et

al. 2022). Estimates for the remaining Baltic Sea countries are derived using a benefit transfer approach.

The recreational benefits for the Baltic Sea countries amount to at least 33.7 billion euros on average per year, following a conservative estimation approach that accounts adult populations only like in the samples where the data come from. The largest total benefits

 $\textbf{Table 6.} \ \ \text{Recreational benefits of the sea use for the Baltic Sea region.}$

Notes. The asterisk marks the study countries from which the values are transferred to other countries. The CS from Finland is transferred to Denmark and Sweden, the CS from Latvia to Estonia, Lithuania, Poland and Russia. The benefit transfer approach is described in chapter 4 and Annex 1. Source: own calculation, based on Ahtiainen et al. (2022), World Bank (2022a). Adult population is estimated to be 75% of the total national population. Please note that the estimate presented is a rough approximation and is subject to refinement in the future. The Baltic Sea coastal population is assumed to be 5% of the total population of Russia.

	Estimated total adult popula- tion (million people) ^a		Total benefits (million € per year)	Confidence
Denmark	4.37	735	3215	Moderate/Low
Estonia	1.00	319	318	Moderate/Low
Finland*	4.15	619	2 567	High
Germany*	62.37	182	11 351	High
Latvia*	1.43	268	382	High
Lithuania	2.10	333	698	Moderate/Low
Poland	28.42	297	8 442	Moderate/Low
Russia ^b	5.40	267	1 443	Moderate/Low
Sweden	7.77	686	5 327	Moderate/Low
Total			33 743	Moderate/Low

are estimated for Germany and Poland while the largest per person estimates occur in Denmark, Sweden and Finland. The per person estimate takes into account the proportion of the population that uses the sea for recreational purposes. Germany has the smallest per person benefits due to a lower percentage of the population participating in recreational activities on the sea (49% compared to 76% in Finland and 79% in Latvia) (Bertram *et al.* 2020).

The confidence in these data is considered high for the countries with original studies and moderate to low for the other countries, as the estimate for these countries relies on value transfer. However, this estimate better captures the recreational benefit generated by the Baltic Sea due to involved non-market values, which are not covered by the estimates based on statistics.

3.2.4 Marine Transport

Marine transport can be divided into two main sectors: transport infrastructure and shipping. Transport infrastructure includes ports and activities related to ports, such as dredging, cargo handling, and water project construction. Shipping includes the transport of both passengers and freight by sea. These two sectors are interconnected, as neither can operate without the other. Shipping may also

include the shipbuilding and repair industry, but these activities are not included in the developed estimates due to a lack of a commonly agreed upon approach and data for estimating their marine-related proportion.

Transport infrastructure

The gross weight of goods handled in all ports is dominated by Germany (Table 7). However, this includes ports on the North Sea, including the large ports of Hamburg and Bremen. To a lesser extent, the values for Denmark and Sweden are also impacted by North Sea ports. Cargo weight has been relatively stable over the past decade, with only Poland having a noticeable increase in traffic (Figure 11). Confidence in these data is moderate. While they are officially reported data gathered from Eurostat, they are not limited to benefits derived from the Baltic Sea.

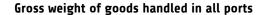
Denmark is the largest marine passenger transport hub in the Baltic Sea region, followed by Sweden (Table 7). Passenger volumes were stable from 2010 to 2019, but the impact of the COVID-19 pandemic can clearly be seen in the 2020 data (Figure 12). Passenger data does not include North Sea ports.

Confidence in these data is high as these are officially reported data gathered from Eurostat.

Table 7. Socio-economic indicators related to transport infrastructure for the most recent data year (2020).

Source: Eurostat 2022d, Eurostat 2022e. Eurostat does not report on Russia. The weight of goods handled includes North Sea ports, unlike the passenger data.

Country	Gross weight of goods handled in all ports (thousand tons) ^b	Passengers embarked and disembarked in all ports (thousand passengers)	Confidence
Denmark	91.4	30859	High
Estonia	37.7	8623	High
Finland	109.2	7357	High
Germany	275.7	4407	High
Latvia	42.1	466	High
Lithuania	51.5	308	High
Poland	88.5	1905	High
Russia ^a	no data	no data	
Sweden	169.0	14020	High
Total	865.2	67945	Good



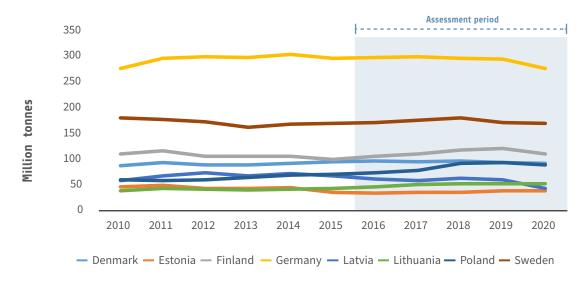


Figure 11. Gross weight of goods handled in all ports (million tons) 2010 – 2020. Shading indicates years included in the HOLAS 3 assessment period. Source: Eurostat 2022d. Eurostat does not report on Russia.

Passengers embarked and disembarked in all ports

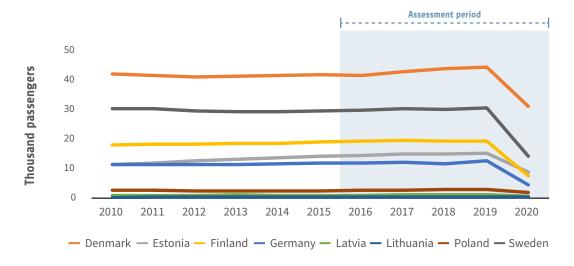


Figure 12. Passengers embarked and disembarked in all ports (thousand persons) 2011 – 2019. Shading indicates years included in the HOLAS 3 assessment period. Source: Eurostat 2022e. Eurostat does not report on Russia.



Shipping

Germany and Denmark lead both employment and value added in the marine freight transport sector (Table 8). Employment has been relatively stable over the past decade, with only minor fluctuations (Figure 13), while value-added has shown much larger changes (Figure 14). During the HOLAS 3 assessment period, Germany and Denmark have had similar levels of employment and value added, despite having had larger differences in the past. Employment in marine passenger transport is more evenly distributed, with Sweden, Finland, Denmark and Germany all having large portions of the total (Table 8). During the HO-LAS 3 period, employment differences among these countries has declined (Figure 15). Value added trends have been more dynamic, with Germany in particular showing very large growth over both the last decade and during the HOLAS 3 assessment period (Figure 16). Value added in Denmark has also grown, while other Baltic countries have remained stable.

Confidence in these data is high as these are officially reported data gathered from Eurostat.

Table 8. Socio-economic indicators related to shipping for the most recent data year (2019). Eurostat 2022f. All monetary values have been adjusted for inflation; constant prices (2015) using Eurostat (2022i). Eurostat does not report on Russia.

Country	Number of persons employed in sea freight transport (FTE)	Number of persons em- ployed in sea passenger transport (FTE)		Value added at factor cost from sea passenger transport (million €)	Confidence
Denmark	9126	4381	4202.0	970.0	HIgh
Estonia	127		14.7	0.0	Hlgh
Finland	2620	4953	329.5	330.1	HIgh
Germany	13946	3511	3472.0	1683.6	Hlgh
Latvia	204	607	16.5	0.0	Hlgh
Lithuania	1002	2	58.1	0.1	Hlgh
Poland	1450	386	94.3	3.5	Hlgh
Russiaª	no data	no data	no data	no data	
Sweden	2560	6344	528.9	413.2	Hlgh
Total	31035	20184	8715.9	3400.4	Good

Employment in marine freight transport

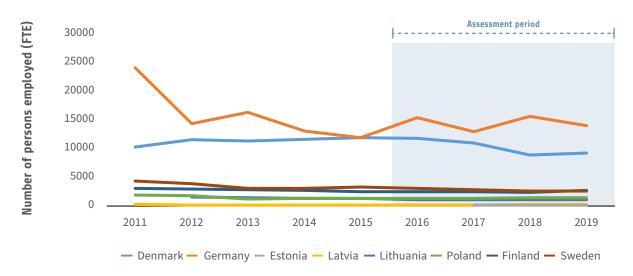


Figure 13. Number of persons employed (FTE) in marine freight transport 2011 – 2019.

Shading indicates years included in the HOLAS 3 assessment period. Source: Eurostat 2022f. Eurostat does not report on Russia.

Value added at factor cost from marine freight transport

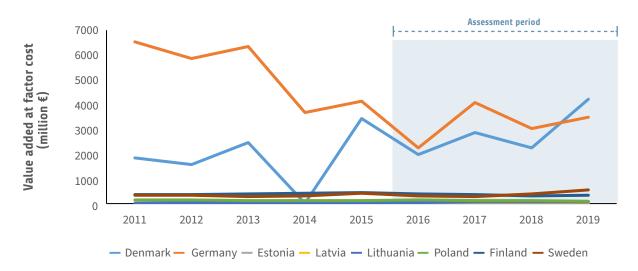


Figure 14. Value added at factor cost from marine freight transport (million €) 2011 – 2019.

Shading indicates years included in the HOLAS 3 assessment period. Source: Eurostat 2022f. All monetary values have been adjusted for inflation; constant prices (2015) using Eurostat (2022i). Eurostat does not report on Russia.

Employment in marine passenger transport

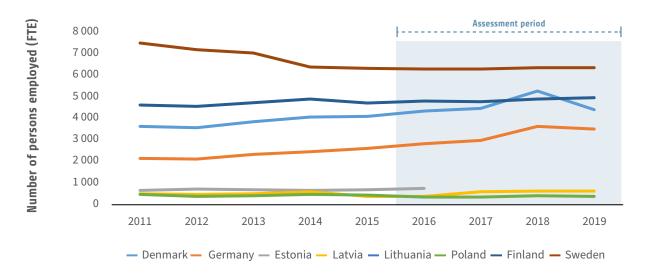


Figure 15. Number of persons employed (FTE) in marine passenger transport 2011 – 2019. Shading indicates years included in the HOLAS 3 assessment period. Source: Eurostat 2022f. Eurostat does not report on Russia.

Value added at factor cost from marine passenger transport

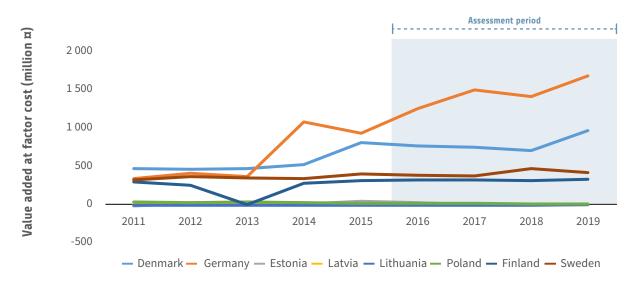


Figure 16. Value added at factor cost from marine passenger transport (million €) 2011 – 2019.

Shading indicates years included in the HOLAS 3 assessment period. Source: Eurostat 2022f. All monetary values have been adjusted for inflation; constant prices (2015) using Eurostat (2022i). Eurostat does not report on Russia.



3.2.5 Renewable energy generation

The Baltic Sea is a growing source of renewable energy produced by offshore wind farms. During the HOLAS 3 period, Germany joined Denmark as major producers of electricity from offshore wind in the Baltic Sea (Figure 17). Sweden is also expected to join this group in the coming years based on the additional capacity approved or under construction (Table 10). Numerous projects are also in the planning phase throughout the Baltic Sea and could receive approval in the near future.

By analyzing the installed production capacity, the national average capacity factor (which is the proportion of production capacity actually used due to varying wind conditions and repair operations), and the annual average wholesale electricity prices, it is possible to estimate the value of the electricity produced by offshore wind in the Baltic Sea. Denmark has been steadily producing approximately 100 million EUR per year over the past decade, with Germany joining it beginning in 2019 (Figure 18). However, in 2021, the value of produced electricity experienced a massive increase due to higher wholesale energy prices resulting from increased international demand following the COVID-19 pandemic.

Confidence in these data is moderate. Data on existing and future capacity and production capacity are or are based on official statistics reported to Eurostat, HELCOM, or a national statistics authority. Data on generated electricity and its wholesale value are based on additional calculations which reduce overall confidence. High variability and increasing electricity prices also reduce confidence in the calculated wholesale value of electricity.

Table 10. Socio-economic indicators related to renewable energy generation for the most recent data year (2021). Source: Eurostat 2022g, Eurostat 2022h, EMODnet 2022a, EC 2021b-e, Swedish Energy Agency 2022. ^a Eurostat does not report on Russia. ^b Finland average capacity factor based on only 2018-2019.

	Total offshore wind electricity generation capacity in the Baltic Sea (MW)	Additional offshore wind electricity genera- tion capacity approved or under construction (MW)		Electricity generated by offshore wind (GWh, estimated)	Estimated wholesale value of electricity gen- erated by offshore wind (million €, estimated)
Denmark	1485.05	0	0.40	5,180	478
Estonia	0	0			0
Finland	73	0	0.39	249	19
Germany	1072.8	1607.7	0.35	3,295	347
Latvia	0	0			0
Lithuania	0	0			0
Poland	0	0			0
Russia	no data	no data	no data	no data	no data
Sweden	173	1722	0.34	519	34
Total	2803.85	3329.7	0.37	9,243	878
Confidence	High - Good	Good - Moderate	Good - Moderate	Moderate - Low	Moderate - Low



Installed offshore wind power capactiy

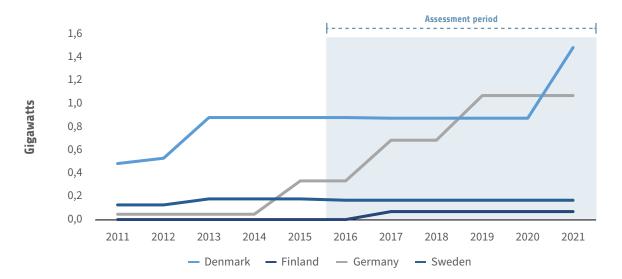


Figure 17. Installed offshore wind power capacity 2011 – 2021.

Shading indicates years included in the HOLAS 3 assessment period. Source: Eurostat 2022g, EMODnet 2022a. Eurostat does not report on Russia.

Estimated wholesale value of electricity generated by offshore wind

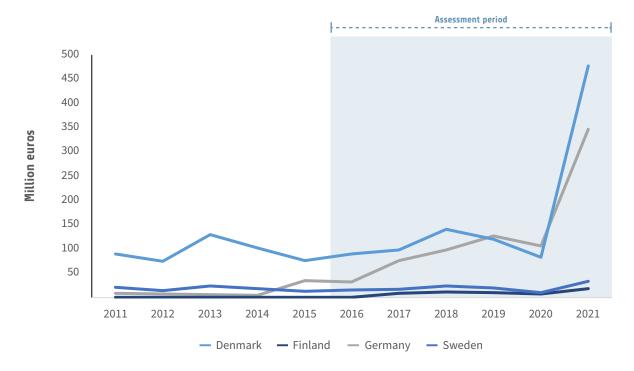


Figure 18. Estimated wholesale value of electricity generated by offshore wind (million €) 2011 – 2021.

Shading indicates years included in the HOLAS 3 assessment period. Source: Eurostat 2022g, Eurostat 2022h, EMODnet 2022a, EC 2022, EC 2021b-e, Swedish Energy Agency 2022. All monetary values have been adjusted for inflation; constant prices (2015) using Eurostat (2022i). Eurostat does not report on Russia.



3.2.6 Extraction of oil and gas

Oil and gas extraction in the Baltic Sea is only conducted in Polish and Russian waters. In Poland the level of activity dropped between 2009 and 2018 (Table 11). Given the ongoing climate crisis, it is expected that regional production will continue to decline in the future. While the central Baltic has been estimated to contain 150 billion cubic meters of natural gas and 1.5 billion barrels of oil, the vast majority is likely unconventional and difficult to extract (USGS 2015).

Confidence in these data is moderate. While they do originate from an official EU report, the methodology relies on unofficial statistics gathered from an industry source.

Table 11. Socio-economic indicators related to extraction of oil and gas (2009, 2018). Source: EC 2021f. All monetary values have been adjusted for inflation; constant prices (2015) using Eurostat (2022i). ^a EC 2021f does not report on Russia.

Country		Number of persons employed in oil and gas extraction and support activities	Value added at factor cost from oil	
Poland	2009	422	20.5	Moderate
Poland	2018	190	7.8	Moderate
Russia ^a	2009	no data	no data	
Russia ^a	2018	no data	no data	

3.2.7 Extraction of minerals

Current extraction of minerals from the Baltic Sea focuses on sand and gravel mining. This primarily occurs in the southern Baltic by Denmark and Germany (Table 12). Mineral extraction has declined or remained relatively stable over the past decade (Figure 19). However, future interest may turn toward manganese deposits present in Baltic sediments.

Confidence in these data is low as they are based on industry estimates.

Table 12. Socio-economic indicators related to extraction of minerals (2019). Source: UEPG 2012-2019. ^a Numbers are based on extraction in both the Baltic Sea and the North Sea.

Country	Marine Aggregates (million tons) ^a	Confidence
Denmark	6.6	Low
Estonia	0	Low
Finland	0	Low
Germany	8	Low
Latvia	0	Low
Lithuania	0	Low
Poland	1	Low
Russia	0	Low
Sweden	0	Low
Total	15.6	Low

Marine aggregate extraction

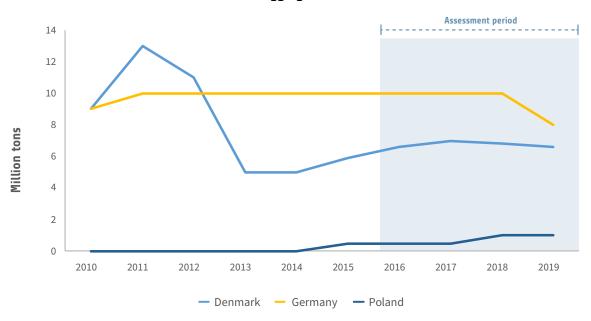


Figure 19. Estimated marine aggregate extraction (2010 – 2019). Source: UEPG 2012–2019.

3.2.8 Waste treatment and disposal

The environment has been used for millennia to treat and dispose of the waste of human societies. It is only in the more recent past that we have recognized the limitations and impacts of this use. However, it is not technically or economically possible to eliminate all waste from entering the environment and the value derived from the use of the marine environment as a source of waste treatment and disposal can be estimated. While this calculation would be relevant for any human waste stream, sufficient data on abatement costs, waste sources and receiving environments in the Baltic Sea only exist for nitrogen and phosphorus.

Despite significant decreases in nutrient inputs to the Baltic Sea since the 1980s (Thematic Assessment of Eutrophication), human activities will continue to pollute the Baltic Sea through waste release and disposal far into the future. In 2017, all human sources combined, including agricultural runoff, emitted 755 thousand tonnes of nitrogen and 22 thousand tonnes of phosphorus into the Baltic Sea (Table 13). If these nutrients had to be removed using existing wastewater treatment technologies, it would cost a minimum of 5.4 billion euros per year (Table 13). The data presented only

includes nutrients from human origins, natural background loads have been removed from nutrient loading estimates.

Poland receives the largest portion of these avoided costs, approximately 1.1 billion € per year combined. Latvia and Lithuania also receive significant avoided costs (783 and 609 million €, respectively); however, the structure of the data distorts their inputs as discussed in the paragraph below.

Confidence in these data is variable. Table 13 accounts for all inputs based on the country from which they enter the Baltic Sea, not the originating country. This is particularly important in the case of Latvia and Lithuania which receive significant nutrient loading originating from upstream countries (Belarus and Russia). This data characteristic makes the national estimates less confident (moderate) than the total Baltic Sea estimate (good). Additionally, the unit prices of nitrogen and phosphorus are the average marginal costs for the Baltic Sea countries for treating that quantity of nutrients. Real costs vary across the countries, depending on various factors (like size of a wastewater treatment plant, the nutrient reduction level). Therefore, the confidence level of the monetary estimates could be seen as moderate.

Table 13. Socio-economic indicators related to waste treatment and disposal. Source: HELCOM (2023a), Hautakangas *et al.* (2014). Nutrient loads based on 2017 data for all countries except Poland (2018). The nutrient load amounts include water-borne loads from upstream non-HELCOM countries, benefiting from the Baltic Sea use. Unit values in 2021 prices.

	Total nitrogen (tonnes)	Unit value of nitrogen				Total benefits of phosphorus disposal (million €)
Denmark	49970		325	1051		21
Estonia	24539		160	495		10
Finland	53217		346	2668		53
Germany	70430		458	795		16
Lithuania	87040	6500 €/t	566	2183	20000 €/t	44
Latvia	110924		721	3083		62
Poland	149623		973	6627		133
Russia	66798		434	2531		51
Sweden	54965		357	1300		26
Total			4911			456
Confidence	Good	Moderate	Moderate	Good	Moderate	Good

3.2.9 Other activities

While the list of assessed activities has expanded from the HOLAS 2 assessment, additional human activities are indicated as relevant either by the MSFD (2008/56/EC) or previous HELCOM work (for example the HELCOM ACTION project: https://helcom.fi/helcom-atwork/projects/action/). The status of these activities is reviewed in Table 14 below.

Table 14. Other human activities of potential relevance to the economic and social analysis of the use of marine waters and an evaluation of their suitability for inclusion in future assessments.

Activity	Current condition of statistics	Discussion
Marine plant and macroalgal harvesting	Statistics available from FAO but are of very poor quality	This should be a target for future expansion of the use of marine waters analysis. A national data call to the relevant countries may be appropriate.
Dredging	No available statistics	While no dredging statistics are available, all dredging is done to support other activities and is, therefore, partially captured in the statistics for those activities (shipping, shipping infrastructure, recreation)
Fish and shellfish processing	Statistics not separated by product source	While fish and shellfish processing statistics are available from Eurostat, they do not distinguish between different origins of the catch. Fish caught outside the Baltic Sea are likely to represent a very large portion of all the fish processed in the Baltic Sea countries. Very detailed industry statistics would be necessary to separate the value originating from the Baltic Sea and are unlikely to become available.
Shipbuilding and repair	Statistics not separated by vessel use (marine vs inland)	While ship building and repair statistics are available from Eurostat, they do not distinguish between vessel uses. However, the activity is dominated by marine uses and could still be a target for future expansion if simple assumptions about use proportions are employed.
Coastal defence and flood protection	Statistics not readily available	The value of Baltic Sea habitats to coastal defence and flood protection is likely very significant. Continued development of regional habitat maps and ecosystem service valuations would allow for inclusion in future analyses.
Hunting and collecting for other purposes	Public statistics not separated by location (inland vs nearshore/offshore)	Seabird hunting is certainly occurring, particularly in Denmark and Southern Finland. Harvest statistics were gathered by data call for HO-LAS 2 but were not updated for HOLAS 3. Additionally, harvest data focuses on the environmental impact rather than the societal benefit. A survey approach supporting the available public data to determine participation in nearshore/offshore hunting would allow for inclusion in future analyses.
Transmission of electricity and communications	Physical statistics available, monetization uncertain	This could be a target for future expansion of the use of marine waters analysis. Monetization would require more significant resources.
Research, survey and educational activities	No available statistics	The independent socio-economic value of these activities would be difficult to estimate because they either support other activities (such as oil and gas extraction or fishing) or benefit education and basic science in less directly monetizable ways.
Other offshore structures	Little or no impact in the Baltic Sea region	
Extraction of salt	Little or no impact in the Baltic Sea region	
Extraction of water	Little or no impact in the Baltic Sea region	





3.3. Relationship of use of marine waters assessment to drivers and pressures

The economic and social analysis of the use of marine waters highlights the benefits society receives from the use of the Baltic Sea. However, these uses typically generate pressures which in turn impact the environment. The results of this assessment are linked to other assessments such as the cost of degradation assessment (chapter 4), ecosystem services assessment (chapter 5), and the Thematic Assessment of Spatial Distribution of Pressures and Impacts, which all provide additional insights into the complex relationship between human activities and the environment in the Baltic Sea region.



3.4. How was the socio-economic assessment of the use of marine waters carried out?

The socio-economic assessment of the use of marine waters utilizes a mixed approach, which builds primarily on the national accounts approach but also adds estimates based on the ecosystem services approach. The emphasis on the national accounts approach is a consequence of data availability: statistics for marine sectors and activities are more readily available than ecosystem service data and values. All data was sourced from publicly available datasets, primarily Eurostat but also various EU and sectoral reports. No additional corrections were made if data were specific to the country rather than the Baltic Sea. This primarily impacts North Sea countries (Denmark, Germany, Sweden). Only indicators for which standardized data were available across the majority of Baltic Sea countries were used. Russian data was frequently unavailable. The indicators value-added and employment were used when available; alternative indicators which characterize the activity were used otherwise.

A shortcoming of employing only the national accounts approach is that the statistics exclude uses of the environment that are non-consumptive and/or are hard or impossible to measure using market prices. To overcome this, the approach supplements the existing statistical indicators with indicators found in the scientific literature that measure non-market benefits from the sea uses, for example recreation and waste treatment and disposal.

Activities included in the analysis were based on MSFD Annex III (list of activities and sectors) and previous HELCOM work. All monetary values which were presented for multiple years were converted to 2015 euros using Eurostat's Harmonized index of consumer prices (Eurostat 2022i).



3.5. Follow up and needs for the future with regards to the economic and social analysis of the use of marine waters

Future work can focus on several issues to improve the quality of this assessment.

- 1. Improve availability of Russian data.
- 2. Expand the assessment to include additional activities as noted in the other activities section
- Expand the use of ecosystem services approach to additional topics and develop regional ecosystem accounting capacity.

HELCOM is already addressing some of these issues through ongoing work on ecosystem services and ecosystem accounting in line with Baltic Sea Action Plan actions HT18 and HT19.



4. Results for the cost of degradation assessment



Assessment results in short

- Achieving good environmental status in national marine waters in the Baltic Sea region by 2040 is projected to provide an annual economic benefit of 5.6 billion euros to the region's population. This estimate is based on individuals' willingness-to-pay for improved environmental conditions, ranging from 13€ (Russia) to 111€ (Denmark) per person per year. Benefit transfer was required to generate estimates for five of the nine Baltic Sea countries, which increases the estimate's uncertainty.
- The region is also estimated to be missing out on 9 billion euros in recreational benefits per year due to degraded environmental conditions. This estimate is based on individual forgone benefit estimates, ranging from 33€ (Russia) to 206€ (Denmark) per person per year.
- Benefit transfer was required to generate estimates for six of the nine Baltic Sea countries, which increases the uncertainty of these estimates.
- These estimates provide two overlapping perspectives on the cost of environmental degradation in the Baltic Sea and should not be summed.



4.1. Introduction to the cost of degradation assessment

Degradation of the marine environment reduces the ecosystem's ability to produce goods and services to society, known as ecosystem services (Millennium Ecosystem Assessment 2005). The ecosystem services provided by marine environments shape the benefits society receives, which in turn influence human well-being. (Fisher *et al.* 2008).

A healthy marine environment offers many benefits including clean and oxygen-rich waters, bountiful fish stocks, safe fish and seafood for consumption, appealing coastal and beach areas, and a diverse marine biodiversity. Failure to attain good marine environmental status would have negative impacts on different segments of society such as recreational enthusiasts (due to reduced recreational opportunities), fishers (due to diminished fish stocks), other citizens (due to adverse impacts on human health), or even future generations.

The term cost of degradation refers to the benefits forgone by society due to not achieving good environmental status (GES) of

the marine environment. These costs include both use and nonuse value losses:

- Use values are the benefits people get through directly using the marine environment, such as recreation or real estate. For example, Artell (2014) found that deterioration in water quality can represent losses up to 32 thousand euros in the value of each unbuilt waterfront summer house lot in Finland.
- Non-use values are the benefits people place on the marine environment even if they do not directly use or come in contact with it, such as existence of marine biodiversity. For example, Ressureição et al. (2012) estimated value losses due to marine biodiversity changes in Poland, including a one-time value loss of 58 USD per resident due to the loss of one mammal species or 20 USD per resident due to losses of between 4 and 10 algae species.

The process of assigning a value to the costs of degradation of the marine environment is called valuation. It is possible to quantify the cost of degradation in monetary terms by identifying

trade-offs that individuals are willing to make between achieving a good marine environment and other goods and services, typically money or income (Segerson 2017). Hence, the cost of degradation per person is the maximum amount of something else that the person would be willing to give up in exchange to have access to or use a good marine environment (Dupuit 1844) (Vatin *et al.* 2016). This amount is determined through surveys asking questions to parts of society that will be impacted by not achieving GES of the marine environment.

To infer the value of the changes in the marine environment, two terms are borrowed from welfare economics. These are consumer surplus and willingness-to-pay (WTP):

- Consumer surplus is the excess value an individual gets from purchasing a good. Since many goods that the marine environment provides do not have a price, the consumer surplus can represent the total value of a good or service. For example, Vesterinen et al. (2010) found that an improvement in water clarity by one meter increases the recreational (use) value per year per Finnish swimmer by between 7.85€ and 23.69€. The welfare measure calculated is consumer surplus.
- Willingness-to-pay (WTP) is the maximum amount of money a person is willing to pay to avoid the degradation of the marine environment. For example, Kosenius and Markku (2015) estimated that doubling the amount of healthy vegetation in the Finnish-Swedish archipelago and the Lithuanian coast is worth 105€, 209€, and 44€ per person in Finland, Sweden, and Lithuania, respectively. The welfare measure calculated is WTP.

Since the previous HOLAS report, new research has estimated the cost of degradation in different Baltic Sea countries. This body of research uses two types of methods: stated and revealed preference methods. Stated preference methods are based on carefully constructed surveys that ask people's willingness to pay for changes in the marine environment (Bateman *et al.* 2002). These methods can capture both use and non-use values related to degradation of the marine environment. Revealed preference methods are based on observing people's behaviour to determine environmental values (Bockstael & McConnel 2007). These methods are able to estimate use values loss related to the degradation of the marine environment, for example recreation value losses

Instead of conducting new research, existing cost of degradation estimates can be transferred to countries where information is missing. This method is known as benefit transfer, whose objective is to get reliable estimates of value when new and original research is not feasible or available (Rosenberger & Loomis 2017). Existing value information needs to be adapted to a new context, by accounting for, for example, differences in income, purchasing power parity, or size of the environmental good. Given the new methodological advances in the past years, newer studies are preferred if available. General recommendations on how to conduct benefit transfer can be seen in Box 1.

Two environmental goods are considered in this cost of degradation analysis: GES and recreation. MSFD (2008/56/EC) defines GES as "the environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive within their intrinsic conditions, and the use of the marine environment is at a level that is sustainable, thus safeguarding the potential for uses and activities by cur-

rent and future generations". The need to achieve GES of marine ecosystems is reiterated in the EU Biodiversity Strategy for 2030 (adopted in 2020). The HELCOM Baltic Sea Action Plan (HELCOM 2021) is the main policy framework for the Baltic Sea region calling for the attainment of GES.

Recreation involves the participation in any outdoor leisure activity, such as swimming or boating. Recreation is typically a public good, with both free entry and no consumption restrictions (Phaneuf and Requate 2016). Studies show that the value of marine-based recreation for the Baltic Sea countries is substantial (for instance, Czajkowski *et al.* (2015), Ahtiainen *et al.* (2022).



4.2. Details on the assessment results for cost of degradation

The cost of degradation assessment is based on studies estimating the benefits for the Baltic Sea countries of 1) achieving GES of the marine environment, and 2) changes in recreational benefits for citizens from an improved state of the marine environment. These studies estimate in welfare terms a gap between GES and a reference state (commonly considered to be the current state but can be a business-as-usual scenario). These are foregone benefits or cost of degradation without actions to achieve GES. The used studies provide estimates expressed in euros per person per year, and are presented also as aggregated costs of degradation.

4.2.1 Cost of degradation from not achieving Good Environmental Status

The assessment of the cost of degradation is based on the willingness to pay (WTP) of citizens for achieving GES. It covers all environmental problems, where the status fails environmental targets, including state of the marine biodiversity and fish stocks, nutrient pollution causing eutrophication, pollution with hazardous sub-



Box 1

Recommendations to properly conduct benefit transfer (adapted from Rosenberger & Loomis 2017):

- 1. Similar policy and study site
- 2. Same or close geographic area
- Adjust value to the affected population and its characteristics
- 4. Similar welfare measures
- Original analysis was conceptually, empirically and theoretically sound

stances, and physical impacts (including marine litter¹ and underwater noise). The four studies used in the analysis describe GES in

A recent study by Khedr et al. (2023) estimates willingness to pay for the reduction of marine litter in eight European countries, including in Denmark, Sweden, Estonia and Germany. They find willingness to pay for reducing marine litter in the country's own coastal area to Marine Strategy Framework Directive requirements exceeding the values presented in the present analysis. As the present analysis focuses on reaching GES, which encompasses marine litter status, the difference in values should be discussed. The different choice of value elicitation methodology and the valuation question may offer some explanation in addition to randomness. Khedr et al. (2023) employ discrete choice experiment method instead of contingent valuation method, which can produce higher value estimates (see e.g. Huber and Finger 2019). Also, the valuation scenario Khedr et al. (2023) occurs ten years (2030) sooner than the studies in the analysis (2040). Finally, the valuation question includes environmental status which may implicitly embed other factors than marine litter and micro-plastics in respondents' minds when answering the valuation question.

line with the MSFD requirements and related environmental targets for each included environmental problem, ensuring undisturbed by pressures, diverse and balanced habitats and populations of living organisms. The four original studies cover Latvian (AKTiiVS 2022), Finnish (Nieminen et al. 2019), Swedish (Nordzell et al. 2020) and German (Oehlmann et al. 2021) marine waters. The benefits of achieving GES are valued comparing to the current state in the Finnish, Swedish and German studies and comparing to a business-as-usual scenario in the Latvian study. The values from these studies are transferred to Danish, Estonian, Lithuanian, Polish and Russian marine waters.

The WTP for reaching GES in national waters by the year 2040, covering all valued problems of the marine environment, is presented in Figure 20 and Table 15. In the original studies, values range from 14 (Latvia) to 94 (Finland) Euros annually per person. The studies cover three of the four higher income countries, namely Germany, Finland and Sweden, and Latvia from the lower income coun-

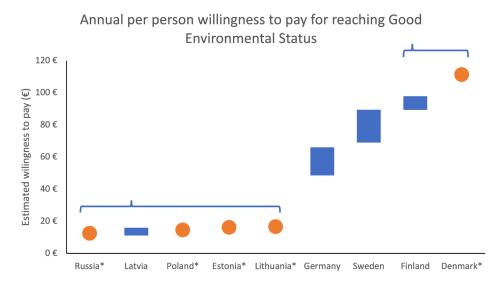


Figure 20. Annual per person willingness to pay (€) for reaching Good Environmental Status of national waters in the Baltic Sea countries.

Table 15. Annual per person willingness to pay (€) and aggregated cost of degradation for reaching Good Environmental Status from current state of national waters in the Baltic Sea countries.

Country	Low (95% confidence interval)		High (95% confidence interval)		Aggregated mean for the population	Original study	Confidence
Denmark*		111€		Finland	485 M€		Moderate
Estonia*		16€		Latvia	16 M€		Moderate
Finland	89€	94€	98€		390 M€	Nieminen <i>et al</i> . 2019	High
Germany	49€	57€	66€		3 555 M€	Oehlmann <i>et al.</i> 2021	High
Latvia	11€	14€	16€		20 M€	AKTiiVS 2022	High
Lithuania*		17€		Latvia	36 M€		Moderate
Poland*		15€		Latvia	426 M€		Moderate
Russia*		13€		Latvia	70 M€		Moderate
Sweden	69€	79€	89€		613 M€	Nordzell <i>et al.</i> 2020	High

tries. According to the procedure explained in Section 4.4, Finnish estimates are transferred to the Danish population, and as the Danish GDP is larger than Finland's, the transferred estimate is slightly higher than the original value. Similarly, Latvian estimates are transferred to Russian, Polish, Estonian and Lithuanian populations.

The blue bars represent the 95 per cent confidence intervals of the willingness to pay per person of the four original studies. The orange dots represent the transferred mean values (country name followed by *). The spike in the curly brackets indicates the source value, and the extent of the brackets shows the countries where the results have been transferred to. A caveat in these results is that, while the transfer method chosen has been shown to produce the smallest errors in the Baltic Sea area (Czajkowski *et al. 2017)*, the transferred values are still subject to errors. Thus, these estimates have moderate confidence. Sources: World Bank 2022b-c, OECD 2022, Eurostat 2022l, AKTiiVS 2022, Nieminen *et al.* 2019, Nordzell *et al.* 2020, Oehlmann *et al.* 2021.

Means and 95 per cent confidence intervals reported for countries with original studies, transferred means reported for other countries. Annual values per person reported in year 2020 purchasing power parity corrected Euros for EU-27 countries. Sources: World Bank 2022b-c, OECD 2022, Eurostat 2022l, AKTiiVS 2022, Nieminen et al. 2019, Nordzell et al. 2020, Oehlmann et al. 2021.

4.2.2 Foregone recreational benefits in the current state of the marine environment

Instead of eliciting WTP to achieve GES, the cost of degradation can be inferred by assessing how recreational benefits would change if the state of the marine environment were to improve. This cost of degradation analysis for Baltic Sea recreation is based on two studies: Ahtiainen *et al.* (2022) and Bertram *et al.* (2020). Both studies use the same data, but the values of a recreational trip from Ahtiainen *et al.* (2022) are used to obtain a more conservative estimate, and then supplemented with the estimated change in trip frequency for an improvement in the Baltic Sea environmental conditions reported

in Bertram *et al.* (2020). Bertram *et al.* (2020) estimates the change in leisure trip frequency to the Baltic Sea due to an improvement in environmental indicators to the best environmental conditions. Compared to the previous assessment, which looks at all relevant aspects of GES, this study does not cover improvements in fish stocks or decreases in hazardous substances or physical impacts like marine litter, which could increase trip frequencies further. The cost of degradation is the estimated difference in the benefits from the current recreational use of the Baltic Sea and the use in the best environmental conditions.

Ahtiainen *et al.* (2022) provide estimates for three countries – Finland, Germany and Latvia, and these estimates are transferred to other Baltic Sea countries. The values for the below median income countries (Russia, Poland, Estonia and Lithuania) are transferred from the Latvian study. For the above median countries, the Swedish and Danish value estimates are transferred from the Finnish study, having – due to higher GDP than Finland – higher value estimates.

The recreational benefit transfers make critical assumptions about the visitation rates and their changes across countries. In addition to assuming similar values per visit across study and policy countries, it also assumes similar patterns and changes in recreation behaviour due to improved quality of the Baltic Sea. As the Latvian results predict both the smallest per visit values and increases in visitation rates under the best environmental quality, the same are assumed also for Russia, Poland, Estonia and Lithuania. The same goes for the share of non-visitors which is assumed the same as Latvia's 21%. On the other hand, transferring the Finnish results to Sweden and Denmark carries implicitly a slightly higher change in visitation rates, but a slightly higher share of non-users, 24%. Thus, there is a higher degree of uncertainty in the benefit transfer related to recreation compared to the GES. Compared to HOLAS II, the new studies show markedly higher per visit values for Latvia, and higher Baltic Sea recreation participation rates for all countries. Overall, the confidence in this assessment is moderate to low depending on the number of assumptions required for each national estimate.

Annual recreation benefits for reaching best environmental state from current state

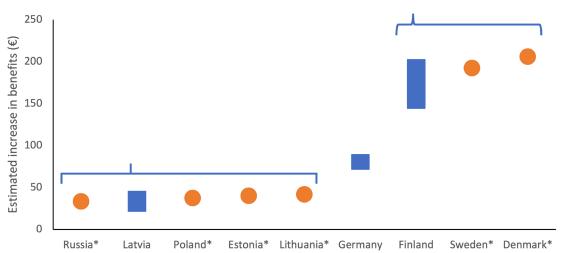


Figure 21. Changes in annual recreational benefits (€ per person) comparing the best environmental state with the current environmental state.

Table 16. Changes in annual recreational benefits (€ per person) comparing the best environmental state with the current environmental state of the national waters in the Baltic Sea countries.

Country	Low (95% confidence interval)		High (95% confidence interval)		Mean change in number of visits	Aggregated mean for the population	Original study	Confidence
Denmark*		206€		Finland		901 M€		Moderate-Low
Estonia*		40€		Latvia		40 M€		Moderate-Low
Finland	144€	173€	202€		28% (2.8 visits)	717 M€	Ahtiainen <i>et al.</i> 2022 Bertram <i>et al.</i> 2020	Good
Germany	72€	80€	89€		44% (1.9 visits)	4 990 M€	Ahtiainen <i>et al.</i> 2022 Bertram <i>et al.</i> 2020	Good
Latvia	21€	34€	46€		12.5% (0.6 visits)	48 M€	Ahtiainen <i>et al.</i> 2022 Bertram <i>et al.</i> 2020	Good
Lithuania*		42€		Latvia		88 M€		Moderate-Low
Poland*		37€		Latvia		1 052 M€		Moderate-Low
Russia*		33€		Latvia		178 M€		Moderate-Low
Sweden*		192€		Finland		1491 M€		Moderate-Low

The blue bars represent 95 per cent confidence intervals of the change in the value per trip in the original study. The orange dots represent the transferred mean values (country name followed by *). The spike in the curly brackets indicates the source value, and the extent of the brackets shows the countries where the results have been transferred to. Annual values per person reported in year 2020 purchasing power parity corrected Euros for EU-27 countries. Sources: World Bank 2022b-c, OECD 2022, Eurostat 2022l, Ahtiainen *et al.* 2022, Bertram *et al.* 2020.

Means and 95 per cent confidence intervals reported for countries with original studies, transferred means reported for other countries. Sources: World Bank 2022b-c, OECD 2022, Eurostat 2022l, Ahtiainen *et al.* 2022, Bertram *et al.* 2020.



4.3. Changes over time for the cost of degradation assessment

New research on economic valuation has emerged since the HOLAS 2 economic and social analyses in the Baltic Sea region 2011-2016 (HELCOM 2018). The former analysis focused on costs of degradation caused by eutrophication, thus offering a partial view of the cost of degradation from not achieving GES. This analysis updates the costs of degradation with recent research conducted in the Baltic Sea region, covering all relevant problems of the marine environment.

While cost of degradation estimates for recreation are included in both HOLAS 2 and HOLAS 3, the underlying surveys are sufficiently different to discourage comparison. The surveys evaluated both different time periods and different measures of environmental improvement.



4.4. Relationship of cost of degradation to drivers and pressures

The cost of degradation analysis highlights the costs to society from environmental degradation of the Baltic Sea, covering all relevant pressures on the marine environment. The results of this assessment are linked to other assessments, such as the use of marine waters assessment (chapter 3), ecosystem services assessment (chapter 5), and the Thematic Assessment of Spatial Distribution of Pressures and Impacts.



4.5. How was the assessment of cost of degradation carried out?

The cost of degradation assessment is based on studies published during the HOLAS 3 period that provide estimates for at least three countries representing a variety of socio-economic and cultural contexts across the countries in the Baltic Sea region. As the studies do not encompass all countries, the benefit transfer method was used to generate estimates for countries without primary valuation studies.

The studies valuing benefits of achieving GES based on WTP are based on several national surveys, where data have been collected from nationally representative samples in 2017 for the Finnish study, in 2020 for the Swedish and German studies and in 2021 for the Latvian study. All studies applied the contingent valuation method, using similar surveys, and included all environmental problems, which prevent achievement of GES according to assessments for the national marine waters. The valued scenarios are described in Annex 1.



The used studies on recreational benefits have been implemented in 2016-2017 by applying identical surveys in all the three countries (Finland, Germany and Latvia). The data were collected from nationally representative samples in each country. Changes in recreational trips have been measured for various improvement levels. The scenario used for this assessment takes estimates for the best possible conditions.

The benefit transfer follows the same procedure employed in HO-LAS 2, where the most appropriate study site (study country hereafter) values are transferred to the policy site (country) using value transfer methodology. First, the study site values (benefit estimates in Euros per person per year) are corrected for inflation between the year of the original study and year 2020 using the rate of change in policy country's consumer price index. Second, the transferred values were made comparable across countries using purchasing power parities for EU-27 countries at year 2020 price levels. Third, the transferred values were corrected to take account of the relative difference in income levels represented by the gross domestic product in the study and policy countries. The most appropriate study country for a policy country was chosen in the analysis so that the nine Baltic Sea countries were divided to two income groups: countries above median gross domestic product (Denmark, Finland, Germany and Sweden) and below (Estonia, Latvia, Lithuania, Poland and Russia). Furthermore, if two or more studies were available for transfer, values were transferred from the study country with the smallest transfer error in the Czajkowski et al. (2017) background data. In Czajkowski et al. (2017) the median transfer error in country-to-country transfers was an over- or underestimation of true value by approximately 50 per cent. The full methodology can be found in Annex 1.

When using existing valuation studies, there is a need to analyse and adjust, if necessary, the values according to scope of environmental changes in the policy scenarios, by comparing the difference between GES and the current state in HOLAS 3 and what was valued in the used studies. Changes in the marginal monetary values are not linear with changes in the environmental quality. The marginal values are diminishing in quantity, meaning that values per unit of environmental change decrease as the size of the environmental change increases (Johnston et al. 2015). In the developed assessment, like also in HOLAS 2, no value scaling considering the extent of environmental change was done to correct the estimates from the valuation studies, but rather the original estimates are assumed to reflect reasonably well the cost of degradation from not achieving GES. Such an assumption produces uncertainty in the estimates (Johnston et al. 2015). Simple approaches to correct for scope differences do not exist, and such approaches likewise rely on assumptions. There are some general principles for scaling value estimates, however future research is needed to develop an approach that could be applied for the sea region assessments, including, for instance, development of quantitative marginal value functions. HELCOM BLUES project has done a systematic literature review on the valuation studies in the Baltic Sea region, providing a valuation study database, which serves as an information base for developing such an approach.



4.6. Follow up and needs for the future with regards to cost of degradation

The updated HELCOM Baltic Sea Action Plan (HELCOM 2021) includes an action on integrating economic and social analyses in HELCOM work strands to allow for assessment of the linkages between the marine environment and human well-being, including carrying out regionally coordinated economic and social analysis of the marine environment (HT15). The cost of degradation analysis highlights the costs to society from environmental degradation of the Baltic Sea, serving as a tool for translating changes in the state of marine environment into changes in human well-being impacts. The assessment has been developed based on available original valuation studies in the Baltic Sea countries, which address relevant needs, covering, as much as possible, all relevant environmental problems preventing achievement of GES in the Baltic Sea and diversity of the sea region countries. However, a benefit transfer had to be applied to provide the sea region scale estimates, and the developed estimates indicate considerable uncertainty in the assessment results. There is a need for coordinated valuation studies to improve the confidence level of the sea region assessment. HELCOM could direct effort to coordinating relevant scientific research and the calendar of HELCOM and the MSFD to improve the assessments dependent on environmental valuation studies, such as the cost of degradation, which has limited data currently.



5. Results for the ecosystem services assessment



Assessment results in short

- The Baltic Sea ecosystem provides a range of goods and services, including wild fish and algae
 for nutrition, regulation and maintenance of the ecosystem through processes such as carbon
 sequestration, and non-material gains from recreational interactions with the ecosystem.
- The average estimated monetary value of the benefits provided by wild fish for human and animal nutrition is 996 to 2576 million euros per year, while the estimated value of the benefits provided by fish cultivated through in-situ aquaculture is 382 to 1046 million euros per year.
- The Baltic Sea's natural processes of carbon sequestration, including through the actions of eelgrass meadows and soft-bottom sediments (sometimes referred to as accumulation bottom sediments), sequester a total of 4.23 million tonnes of carbon annually, with an estimated monetary value of 622-1554 million euros per year, respectively. In addition, the estimated monetary benefits for the countries surrounding the Baltic Sea average 5.45 billion euros per year for nitrogen sequestration and 4.97 billion euros per year for phosphorus sequestration.
- Assessment outcomes include cultural ecosystem service valuation illustrations from recent studies within the Baltic Sea, and a green infrastructure map highlighting areas with high ES supply potential for various uses including maritime spatial planning. Outcomes demonstrate that ecosystem services provide significant economic and societal value, highlighting the importance of protecting and managing the Baltic Sea ecosystem.



5.1. Introduction to the ecosystem services assessment

5.1.1 The ecosystem service approach

Ecosystem services (ES) are the direct and indirect contributions ecosystems make to human well-being, arising from the interaction of biotic and abiotic processes (Potschin & Haines-Young 2016b), and they are fundamental to the well-being of humanity. ES are generated by functions and processes of the ecosystem and provide goods, like wild fish and algae to nutrition, regulation and maintenance of the ecosystem, like carbon sequestration, and non-material gains from interacting with the ecosystem, like recreation. The ES approach is a common method in

environmental policy and management, used to understand and conceptualize interactions between ecosystems and human well-being. This approach can be seen as a way of understanding the complex relationship between nature and society, to support decision and policy making with the aim of ensuring the sustainable use of resources (Martin-Ortega *et al.* 2015).

The ES approach and its offshoot ecosystem accounting are regarded as particularly important developing tools for environmental management. Unlike other environment focused tools, such as environmental indicators, they link ecosystem state to societal well-being. They have better capacity than other socio-economic assessment tools to evaluate trade-offs between alternative sea use, management and protection options. How-



ever, both the ES approach and the ecosystem accounting need further resources and development in terms of their knowledge and information base, compared to the more established environmental management and assessment tools.

The ES assessments can be used for the economic and social analysis of the use of marine waters to demonstrate the socio-economic benefits from use of the sea. They can also provide assessment of well-being impacts of degradation of the marine environment (cost of degradation) or improving the ecosystem state, providing input for discussions on costs and benefits of implementing measures and achieving GES. Spatial assessments of ES allow for exploring complex location-oriented environmental and sea use issues to support policy making. This assessment provides considerable advancement towards use of the ES approach on the sea region scale to support policy making for protection and sustainable use of the Baltic Sea.

5.1.2 Ecosystem service classification and definitions

Working with the ES assessment requires clear and consistent definitions of the assessment elements and the ES typology. For the developed assessment, the assessment elements are defined as follows (Potschin and Haines-Young 2016b) (Burkhard *et al.* 2012):

- ES Supply: ES supply represents physical flows of final ecosystem services from ecosystems to beneficiaries and they are directly affected or used by people". In this assessment, potential ES supply was used.
- ES Benefits: The direct and indirect outputs from ecosystems
 that have been turned into products or experiences that are no
 longer functionally connected to the systems from which they
 were derived. Benefits are things that can be valued either in
 monetary or social terms.
- Values: The criteria by which people assign/justify importance to/of things. Values can be individual or collective and can be qualitative or quantitative. The definition recognises that ecosystem services can embrace different types of values that cannot be reduced to one (monetary) type.
- Human well-being: Human well-being is that which arises from adequate access to the basic materials for a good life, that are needed to sustain freedom of choice and action, health, good social relations and security. The state of well-being is dependent on the aggregated output of ecosystem benefits and is thus distinct from individual benefits

Ecosystem services are classified in three categories according to the Common International Classification of Ecosystem Services (CICES) (Potschin and Haines-Young 2018):

- **1. Provisioning ecosystem services:** Provisioning ES are all nutritional, non-nutritional material and energetic outputs from living systems as well as abiotic outputs (including water).
- 2. Regulation and Maintenance Ecosystem Services: Regulation and maintenance ES are defined as the ways in which living organisms can mediate or moderate the ambient environment that affects human health, safety, or comfort, together with abiotic equivalents.
- **3. Cultural Ecosystem Services:** Cultural ES are all the non-material, and normally non-rival and non-consumptive, outputs of ecosystems (biotic and abiotic) that affect physical and mental states of people.

The developed ES list for the assessment (Table 17) is based on the ES classification CICES V5.1, the ES relevant for marine ecosystem (Haines-Young and Potschin 2018). It has been modified to include only the relevant ES and combine some CICES classes.

Only biotic ES are considered in the current approach, since the assessment aims to support the marine protection policies (in particular, the HELCOM, EU MSFD, EU Biodiversity Strategy), and primarily the biotic ES are impacted by such policy measures. However, the approach allows inclusion of the abiotic ES also depending on the needs in the future (for instance, coastal and marine water used as energy source; minerals used for material purposes; wind energy; mediation by other chemical or physical means (like via filtration, sequestration, storage or accumulation).

For each ES the corresponding benefits are specified, including the direct benefits only (Table 16). The specifications of the ES and benefits are developed corresponding to the definitions provided above.

The assessment recognises diverse socio-economic values related to the various ES benefits. For instance, wild fish have nutritional value, create income in fisheries and related sectors and employment for inhabitants. The assessment results presented in this section focus on quantitative estimates of the benefits and monetary estimates of the socio-economic values. Estimates on the economic and employment impacts are presented in chapter 3. However, the monetary estimates are complemented with other quantitative data, providing information on additional relevant aspects of the socio-economic values and societal preferences.



Table 17. List of ecosystem services, examples of benefits and their inclusion in HOLAS 3.

^a ES is sub-divided to facilitate linking to the contributing ecosystem components (distinguishing assimilation, storage and sequestration/burial).

ECOS	stem service	Examples of benefits	Inclusion in HOLAS 3
PRO\	ISIONING ECOSYSTEM SERVICES		
P1 Wi	d fish for human and domesticated animal nutrition	Food (various fish products) for human consumption, materials (for instance, fish meal) for domesticated animal nutrition	Estimates on the benefit and socio-economic values to humans
P2 Wi	d algae for nutrition, industrial uses and energy production	Food, for instance, food additives, like algin (sodium alginate) for human consumption, materials for soil fertilisation, cosmetics, resource for energy production	Not included
	nts and animals cultivated by in-situ aquaculture for nutrition, rial uses and energy production	See P1 and P2, but originating from aquaculture	Estimates on the benefit and socio-economic values to humans from fish cultivated by marine aquacultu
P4 Ge	netic materials from plants and animals	Genetic stock to support salmon hatcheries	Not included
REGL	LATION AND MAINTENANCE ECOSYSTEM SERVICES		
lation	RM1.1 Nutrient assimilation (for instance, nutrient uptake by plants and algae) ^a	Assimilation and burial of nutrient excess from human activities	Spatial estimate of the benefit
ent regu	RM1.2 Nutrient storage (for instance, nutrient storage in the tissue of marine organisms) ^a	Nutrients stored in the tissue of marine organisms	Spatial estimate of the benefit
RM1 Nutrient regulation	RM1.3 Nutrient sequestration (for instance, nutrient burial for long periods of time in soft bottom sediments) ^a	Nutrient burial for long periods of time in soft seafloor sediment	Spatial estimate of the benefit and estimate of the socio-economic value to humans. Included in aggre gated ES potential map
RM2 I	lazardous substances accumulation and transformation	Assimilation of hazardous substances from human activities	Not included
ıtion	RM3.1 Carbon assimilation (for instance, carbon uptake by plants and algae from the air or water) ^a	Climate change mitigation and sustained living conditions due to carbon capture and storage, reducing carbon diox- ide and other greenhouse gasses in the atmosphere	Spatial estimate of the benefit
ın regula	RM3.2 Carbon storage (for instance, carbon stored in the tissue of marine organisms) ^a	Carbon stored in the tissue of marine organisms	Spatial estimate of the benefit
RM3 Carbon regulation	RM3.3 Carbon sequestration (for instance, carbon burial for long period of time in soft bottom sediment)*	Carbon burial for long periods of time in soft seafloor sediment	Spatial estimate of the benefit and estimate of the socio-economic value to humans. Included in aggre gated ES potential map
RM4 E	rosion regulation	Protection of seabed and coasts from erosion	Included in aggregated ES potential map
RM5 F	est and disease control (for instance, predation on fly larvae)	Management of pest insect populations	Included in aggregated ES potential map
RM6 [ispersal	(Indirect benefit – larval fish transport after spawning)	Not included
RM7 I	laintenance of habitats and nursery populations	(Indirect benefit – maintenance of macroalgae habitats	Included in aggregated ES potential map
ULT	JRAL ECOSYSTEM SERVICES		
swim	vironment for recreation (for recreational activities such as ming, relaxing on the beach, physical leisure/sport activities, e observation, angling)	Recreational experiences providing such non-material gains as feelings, health, opportunities for social interaction with other people	Estimate on societal benefits from cultural ES related to recreation, illustration on relative importance of benefits from individual cultural ES according to
2 En	vironment for enjoyment of seascape	Aesthetic experiences from enjoyment of the seascape	citizens' preferences, illustration on link between the
orogr	vironment for science and education (for research stations and ams, nature parks, museums, education programs, excursions, ar-science information in mass media)	Knowledge advancement and ocean literacy (the essential principles and fundamental concepts about the functioning of the ocean)	marine environment and the cultural ES
C4 Environment for maintenance of cultural and historical heritage		Opportunities for experiencing sea related historical and cultural places, for maintenance of the sea related traditions and culture	
C5 Environment for spiritual experience		Spiritual emotions and symbols, which create sense of place/belonging and identity, spiritual experience	
C6 Environment for inspiration		Inspiration for artistic work, like photography, producing marine inspired design, music, films, literature, paintings	
C7 Existence of habitats and species		Moral satisfaction from and responsibility for existence and preservation for future generations of the marine habitats and species	
	R ECOSYSTEM SERVICE EVALUATIONS		



5.2. Details on the results for the ecosystem services assessment

5.2.1 Provisioning Ecosystem Services

P1 Wild fish for human and domesticated animal nutrition

Benefits of this ES are assessed by catch of commercially relevant fish species (tonnes per year) based on ICES landing data. Monetary value of the nutrition benefits is estimated based on the market (retail and landing) prices of fish products for relevant fish species (Table 18). The approach assumes that the market price reflects the value attached by consumers to the good in question.

Atlantic herring (Clupea harengus), European sprat (Sprattus sprattus) and Atlantic cod (Gadus morhua) represent more than 90% of the fish caught in the Baltic Sea by weight. The average catch of herring, sprat, cod, and flounder in the period 2016-2021 was 0.647 million tonnes on per year (Table 19). Herring and sprat are widely used also for animal nutrition, and the landing prices reflect better this value. There are no data for each country on proportion of catch that is used for the animal

nutrition, therefore a rough assumption on 50% share is used for the sea region overall. The average estimated monetary value of the benefits is 996-2576 million € per year (Table 18). Confidence in this estimate is moderate, as it is calculated based on a range of prices for various fish products but misses actual data on shares of the various products in the consumption.

P3 Fish cultivated by in-situ aquaculture

Benefits of this ES are assessed by marine aquaculture production volume (tonnes per year) based on STECF data. Monetary value of the benefits is estimated based on market price of the marine aquaculture production (Table 20). The approach assumes that the market price reflects the value attached by consumers to the good in question.

The benefit estimate is based on average production in the period 2016-2018 (Table 20). Trout and mussel are the major species in aquaculture production. The estimated monetary value of the benefits is 382 to 1046 million € on average per year (Table 20). Confidence in this estimate is moderate, since it is calculated based on a range of prices for various products but misses actual data on shares of the various products in the consumption.

Table 18. Unit values (prices) for monetary valuation of the benefits from the ES P1 "Wild fish for human and domesticated animal nutrition". Source: EUMOFAP 2022. a Data for 2020, except flounder which is an average price for 2019–2021. b Data for 2020.

Fish species and their products	Retail/consumption price €/kilogramª	Landing price €/kilogramb
Baltic herring and its products (fillets, in oil, in sauce, canned, rollmops)	3-7.5	0.20
Sprat/sardine (fresh, canned, in oil)	2-7.5	0.17
Cod (fresh, frozen) and its products (whole, gutted, fillets)	6-9	3.0
Flounder (fresh, whole or gutted)	3	1.4

Table 19. Monetary benefits of the ES P1 "Wild fish for human and domesticated animal nutrition" for the Baltic Sea countries. The colour denotes confidence (moderate). Source: EUMOFAP 2022, ICES 2022a-k, own calculation. ^a Does not include catches from Kattegat or the Sound

Fish species	Average catch in the Baltic Sea tonnes/year (2016-2021)	Applied market price €/kilograms	Average monetary benefits million €/ year
Atlantic herring ^a	326 821	3-7.5€ (50%) and 0.20€ (50%)	523 – 1 259
European sprat	285 500	2-7.5€ (50%) and 0.17€ (50%)	310 – 1 095
Atlantic cod	19 585	6-9€	118 – 176
European and Baltic flounder	15 377	3€	46
Total	647 283		997 – 2 576

Table 20. Monetary benefits of the ES P3 "Fish cultivated by in-situ aquaculture" for the Baltic Sea countries. The colour denotes confidence (moderate). Sources: STECF 2021a, EUMOFAP 2022, own calculation.

Species	Average production in the Baltic Sea tonnes/year (2016-2018) ^a	Applied market price €/kilograms ^b	Average monetary benefits million €/ year
Mussel	21 838	2-5€ (aquaculture sales price – fish retail price)	44 – 109
Trout	46 022	6-19€ (fish retail/ consumption prices (2021) in various countries for various products)	276 – 874
Crustaceans	2 297	27€ (aquaculture sales price; average for the Baltic Sea from 2018-2020)	62
Total			382-1046

5.2.2 Regulation and Maintenance Ecosystem Services

This section focuses on the contribution of eelgrass, Fucus spp., and soft-bottom sediment areas to the regulation and maintenance of ecosystem services in the Baltic Sea. While the region is home to a diverse range of aquatic plant species, this report only includes those with detailed data availability.

RM3 Carbon regulation

In the marine environment, carbon is taken up by a variety of organisms by biological fixation during photosynthesis, including macrophytes and phytoplankton. These organisms use carbon to grow and reproduce, storing it in their bodies. When these organisms die, their bodies sink to the sea floor, where they are decomposed by bacteria and other organisms. However, some of the carbon that is taken up by marine organisms is not released back into the environment. Instead, it is sequestered mainly in seafloor accumulation sediments. This ES contributes to the regulation of

atmospheric carbon dioxide and climate stability. Note that the analysis of carbon regulation does not consider the role of secondary production involving predation.

In this assessment, carbon assimilation was not considered a final ecosystem service, but rather an ecosystem function, and therefore a monetary valuation is not performed. In addition, carbon storage is considered a natural capital stock rather than a natural capital flow (ES) (Edens *et al.* 2019). While valuation is possible and appropriate in many circumstances, this assessment focuses on valuing only final ecosystem services, and therefore a monetary valuation is not performed (see Box 4 for more information on marine ecosystem accounting).

1. Carbon assimilation

Carbon assimilation is the process by which inorganic carbon (particularly in the form of carbon dioxide) is converted to organic compounds by living organisms. Benefits of the carbon

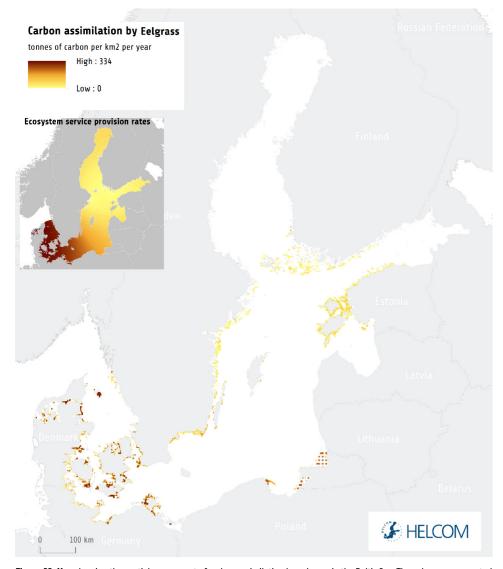


Figure 22. Map showing the spatial assessment of carbon assimilation by eelgrass in the Baltic Sea. The values are presented in tonnes of carbon per km² per year. The smaller map in the upper left corner illustrates the ecosystem service provision rates, which were generated by interpolating data from various scientific sources (Röhr *et al.* 2016, Duarte 1990). The distribution map was produced using data from HELCOM 2023, EMODnet 2022b.

assimilation ES were assessed with respect to provision of this ES by eelgrass (Zostera marina) and Fucus spp. (for example, bladderwrack).

The quantified benefits of eelgrass, considering the estimated habitat area of $5381~\rm km^2$ (see the carbon sequestration section for more information) and assimilation rates from literature, are estimated to be around 1528535 tonnes of carbon assimilated annually. Provision of this service is heterogenous in the Baltic Sea, ranging from 188 to 334 tonnes per km² per year, with the highest rates found in the Danish straits (Figure 22).

The confidence in the general spatial pattern of this estimate is good. The ecosystem function is concentrated in shallow coastal waters in the southern and central Baltic and rates of assimilation are generally higher in the south due to the species' growth characteristics (Boström 2014). However, the confidence in the quantified estimate is low. First, estimates are not directly measured

but calculated from growth rates and tissue carbon content. Additionally, the growth rate data is based on literature from only two sub-regions interpolated across the whole Baltic Sea.

The estimated area of Fucus spp. is approximately 6926 km² in the Baltic Sea based on data submission by HELCOM Contracting Parties and the data processing methodology implemented by the Secretariat. The quantified benefits, considering the estimated Fucus spp. area and assimilation rates from literature, are estimated to be around 58493 tonnes of carbon assimilated annually. Provision of this service is heterogenous in the Baltic Sea, ranging from 4 to 24 tonnes per km² per year, with higher rates found in the south-west Baltic Sea (Figure 23).

The confidence in the general spatial pattern of this estimate is good. The ecosystem function is concentrated in shallow coastal waters. However, the growth rate data was not systematically assessed across latitudes within a single study increas-

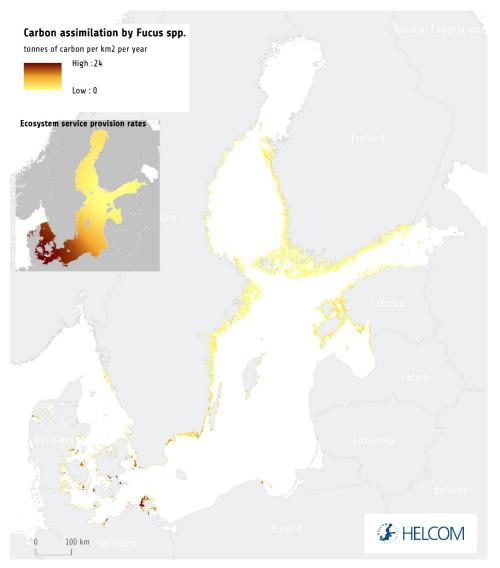


Figure 23. Map showing the spatial assessment of carbon assimilation by Fucus spp. in the Baltic Sea. The values are presented in tonnes of carbon per km² per year. The smaller map in the upper left corner illustrates the ecosystem service provision rates, which were generated by interpolating data from various scientific sources (Lehvo et al. 2001, Graiff et al. 2015). The distribution map was produced using data from HELCOM 2023, EMODnet 2022b, Torn et al. 2006.

ing uncertainty. The confidence in the quantified estimate is low. First, estimates are not directly measured but calculated from growth rates, tissue carbon content, and dry-weight to wet-weight ratios. Additionally, the growth rate data is based on only two points interpolated across the whole Baltic Sea.

2. Carbon storage

Atmospheric carbon enters the Baltic Sea through gas exchange processes at the sea-atmosphere interface. Inorganic carbon is fixed in photosynthesis by primary producers in the Baltic Sea and released again through respiration. Vegetated coastal ecosystems play an important role to store a large percentage of this carbon (Röhr *et al.* 2016). Benefits of the carbon storage ES were assessed with respect to provision of this ES by eelgrass and Fucus spp.

The quantified benefits from eelgrass, considering the estimated habitat area and storage rates from literature, are estimated to be around 6078005 tonnes of carbon in total. Provision of this service is heterogenous in the Baltic Sea, ranging from 324 to 1565 tonnes per km², with higher rates found in the Danish straits (Figure 24). The variations in the rate map can be attributed to the growth characteristics of eelgrass (Boström *et al.* 2014)

The confidence in the general spatial pattern of this estimate is high. However, confidence in the quantified estimate is low. Interpolation was used to generate the whole Baltic Sea rate map and the eelgrass habitat quantity is uncertain.

The quantified benefits from Fucus spp., considering the estimated habitat area and storage rates from literature, are estimated to be around 33806 tonnes of carbon in total. Limited

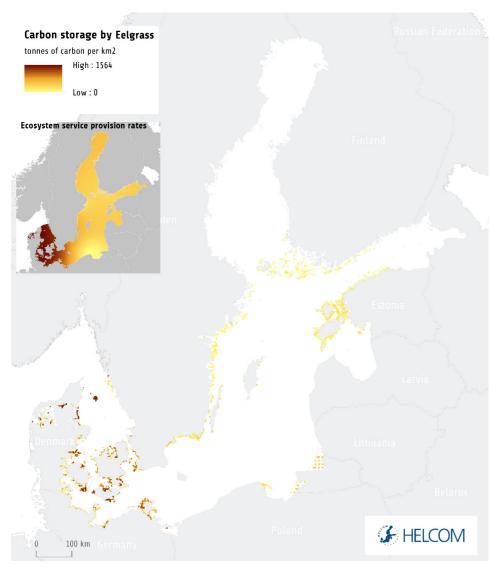


Figure 24. Map showing the spatial assessment of carbon storage by eelgrass in the Baltic Sea. The values are presented in tonnes of carbon per km². The smaller map in the upper left corner illustrates the ecosystem service provision rates, which were generated by interpolating data from various scientific sources (Röhr *et al.* 2016, Jankowska *et al.* 2016, Dahl *et al.* 2016). The distribution map was produced using data from HELCOM 2023, EMODnet 2022b.

availability of literature resulted in no variability in storage rates (Figure 25). However, higher quantities of Fucus spp. present in the northern Baltic result in higher levels of carbon storage.

The confidence is low in this estimate since it relies on data from a single study and single rate, which may not be representative of the entire Baltic Sea and does not capture any natural variation.

3. Carbon Sequestration

Benefits of the carbon sequestration ES were assessed with respect to provision of this ES by eelgrass and soft-bottom sediments.

The estimated area of eelgrass is approximately 5381 km² in the Baltic Sea. Literature estimates place the minimum area of eelgrass in the Baltic Sea region at 1482 km² (Boström *et al.* 2014). These data are not in conflict, however the relatively large difference between them may partially be a result of mixed use of modelled and surveyed presence data submitted by Contracting Parties and their relatively low resolution (1 km²).

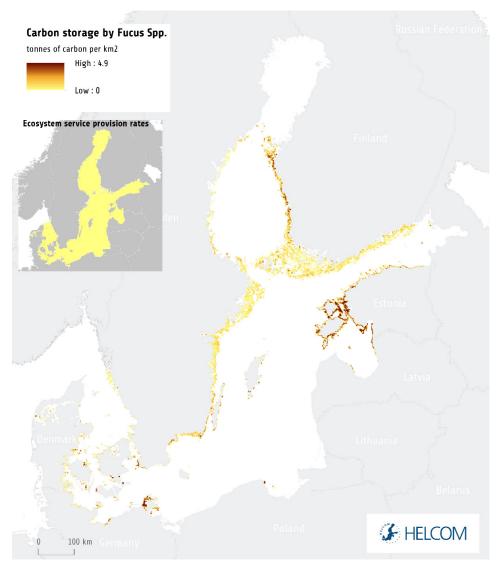


Figure 25. Map showing the spatial assessment of carbon storage by Fucus spp. in the Baltic Sea. The values are presented in tonnes of carbon per km². The smaller map in the upper left corner illustrates the ecosystem service provision rates, which were generated from a single data point from Balina et al. (2015). The distribution map was produced using data from HEL-COM 2023, EMODnet 2022b, Torn et al. 2006.

The quantified benefits, considering the estimated area of eelgrass and sequestration rates from literature, are estimated to be around 120709 tonnes of carbon sequestered annually. Provision of this service is heterogenous in the Baltic Sea, ranging from 3 to 35 tonnes per km² per year with higher rates in the Danish straits (Figure 26). The variation in carbon sequestration rates may be explained by its tendency to grow in more exposed locations in the northern Baltic, which leads to increased export of organic carbon from these areas and incorporation into detrital food webs in deeper areas of the sea (Röhr *et al.* 2016).

The confidence in the general spatial pattern of this estimate is good. However, confidence in the quantified estimate is low. Uncertainty in the estimate of eelgrass habitat in the Baltic Sea, lack of any habitat quality data and use of interpolation to generate a Baltic Sea wide rate map all contribute to the reduced confidence. Soft-bottom sediment areas (circalittoral and infralittoral mud and

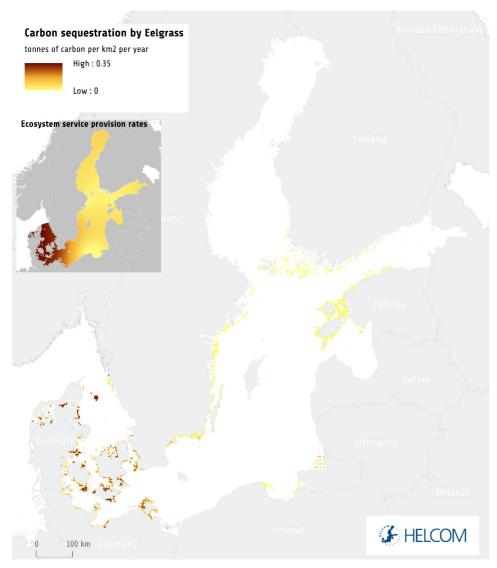


Figure 26. Map showing the spatial assessment of carbon sequestration by eelgrass in the Baltic Sea. The values are presented in tonnes of carbon per km² per year. The smaller map in the upper left corner illustrates the ecosystem service provision rates, which were generated by interpolating data from various scientific sources (Röhr *et al.* 2016, Jankowska *et al.* 2016, Dahl *et al.* 2016). The distribution map was produced using data from HELCOM 2023, EMODnet 2022b.

mixed areas) represent 316134 km² in the Baltic Sea. The quantified benefits, considering the estimated habitat area and sequestration rates from literature, are estimated to be around 4114018 tonnes of carbon sequestered annually. Provision of this service is heterogenous in the Baltic Sea, ranging from 8 to 25 tonnes per km² per year, with the highest rates in the Gulf of Finland (Figure 27).

Confidence is moderate for the carbon sequestration in soft-bottom sediments due to several factors. First, mud and mixed areas were treated equally in this estimation, does not accurately reflect the true distribution pattern of carbon sequestration in these areas. Additionally, the calculation of ecosystem benefit provision rates was performed based on literature for mud sediments, which will cause an over-estimation of carbon sequestration in this assess-

ment. In addition, the use of interpolation techniques and rate variability may introduce additional uncertainty into the estimates.

The well-being impacts of carbon sequestration by eelgrass and soft bottom sediments are estimated in monetary terms, based on avoided costs of the damage to human well-being from carbon emissions. The estimate is based on transferring value of "social costs of carbon" from literature. The "social costs of carbon" is the estimate of monetary value of the damage done from the emission of one more tonne of carbon at some point in time. Using a unit cost interval of 40 to 100 € per tonne of carbon dioxide (Wang *et al.* 2019, High-Level Commission on Carbon Prices 2017), the total estimated monetary benefits for the Baltic Sea countries are 622 to 1554 million € on average per year (Table

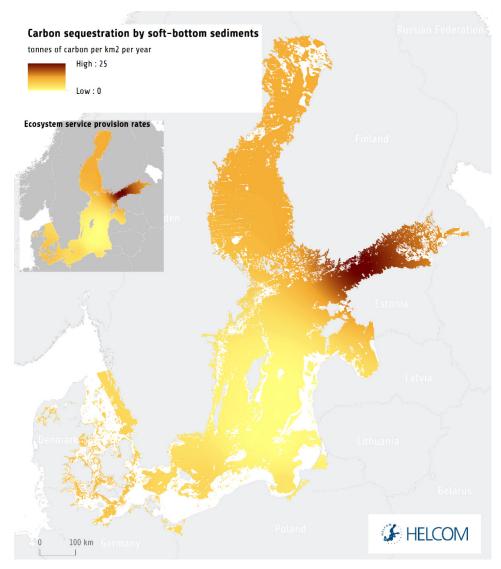


Figure 27. Map showing the spatial assessment of carbon sequestration in soft-bottom sediments in the Baltic Sea (HELCOM 2022). The values are presented in tonnes of carbon per km² per year. The smaller map in the upper left corner illustrates the ecosystem service provision rates, which were generated by interpolating data (sub-basin average values) from Winogradow and Pempkowiak (2013). The distribution map was produced using data from HELCOM 2023.

Table 21. Monetary benefits of the ESRM3 "carbon sequestration" provided by eelgrass and soft bottom sediments in the Baltic Sea. The colour denotes confidence (moderate). Source: own calculations. ^a The interval is calculated using the price interval (40–100 €/tonne) and the total sequestered carbon dioxide (tonnes/year), accounting the estimated habitat area in the Baltic Sea. ^b The first interval is calculated using the average sequestration rate per area unit (tonnes/km²) and the applied unit price range (40–100 €/tonne); the second interval accounts intervals for both the range of sequestration rates (minimum and maximum sequestration rates) and the price range.

	Eelgrass		Soft-bottom sediments	
Ecosystem service	Million €/yearª	€/km²/year ^b	million €/yearª	€/km²/year ^b
Caula de la casa de la	18-44	3293 - 8233	604-1510	1910 – 4776
Carbon sequestration		(408–12918)		(1174 - 9175)

21). In this estimation, the carbon-to-carbon dioxide (CO2) conversion factor of 3.67 was applied to convert carbon (C) weight to CO2 weight. This multiplier accounts for the molecular weight and stoichiometry of the combustion process. Confidence in the estimate is moderate, as it involves transferring the damage costs values from literature.

RM1 Nutrient regulation

Coastal ecosystems play a vital role in processing nutrients that enter the marine environment from inland sources. Nutrient uptake occurs through a process known as nutrient assimilation, in which organisms such as macrophytes take up nutrients from their environment and incorporate them into their biomass. As these organisms grow and reproduce, they store nutrients within their tissues, which can then be passed on to other organisms when they are consumed or when they die, and their biomass decomposes. This process of nutrient retention within the ecosystem is known as nutrient storage and can occur within the bodies and roots of macrophytes until they die and become incorporated into seafloor sediments. However, some of the nutrients taken up by aquatic organisms may become permanently buried in seafloor sediments, in a process known as nutrient sequestration. This sequestered pool of nutrients may remain unavailable for cycling back into the ecosystem over long periods of time. Thus, while nutrient assimilation and storage both involve the uptake and retention of nutrients by organisms within the ecosystem, the latter refers specifically to the long-term retention of nutrients within the ecosystem, rather than their incorporation into biomass, while nutrient sequestration represents a permanent loss of nutrients from the ecosystem.

This analysis focused on eelgrass and Fucus spp. as components providing nutrient assimilation and storage, and soft-bottom sediments for nutrient sequestration. While these services share similarities, such as their contribution to nutrient cycling and their potential to support ecosystem productivity, they are distinct processes with different ecological and biogeochemical implications. We used published ecosystem service provision rate estimates to avoid duplication, though we acknowledge some overlap between services.

In this assessment, nutrient assimilation was not considered a final ecosystem service, but rather an ecosystem function, and therefore a monetary valuation is not performed. In addition, nutrient storage is considered a natural capital stock rather than a natural capital flow (ES). While valuation is possible and appropriate in many circumstances, this assessment focuses on valuing only final ecosystem services, and therefore a monetary valuation is not performed (see Box 4 for more information on marine ecosystem accounting).

1. Nitrogen and phosphorus assimilation

Nitrogen assimilation is the process by which inorganic nitrogen compounds are used to form organic nitrogen compounds such as amino acids, amides, etc. Plants and other organisms, which cannot utilize nitrogen molecules directly, depend on the absorption of nitrogen as nitrates or ammonia. Benefits of the nutrient assimilation ES were assessed with respect to provision of this ES by eelgrass and Fucus spp.

The quantified benefits from eelgrass, considering the estimated habitat area and assimilation rates from literature, are estimated to be approximately 106153 tonnes of nitrogen, and 10615 tonnes of phosphorus annually. Provision of this ES is het-

erogenous in the Baltic Sea, ranging from 13 to 23 tonnes of nitrogen and 1 to 2 tonnes of phosphorus per km² per year, higher rates were found in the south (Figure 28).

The confidence in the general spatial pattern of this estimate is high. The ecosystem function is concentrated in shallow coastal waters in the southern and central Baltic and rates of assimilation are generally higher in the south due to the species' growth characteristics (Boström 2014). However, the confidence in the quantified estimate is low. First, estimates are not directly measured but calculated from growth rates and tissue carbon content. Additionally, the growth rate data is based on only two points interpolated across the whole Baltic Sea.

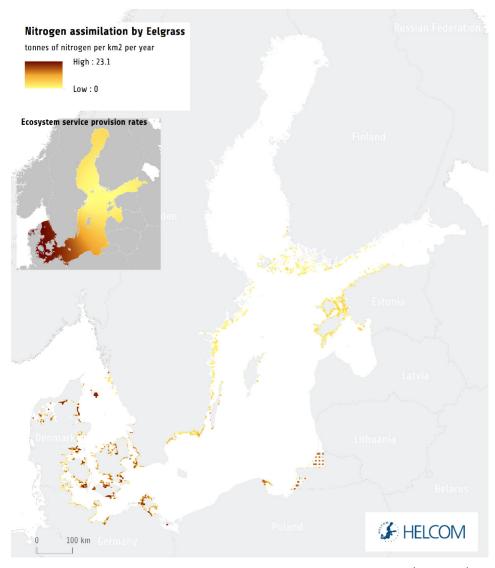


Figure 28. Map showing the spatial assessment of nitrogen assimilation by eelgrass in the Baltic Sea (HELCOM 2022). The values are presented in tonnes of carbon per km². The smaller map in the upper left corner illustrates the ecosystem service provision rates, which were generated by interpolating data from various scientific sources (Röhr *et al.* 2016 and Duarte 1990). The distribution map was produced using data from HELCOM 2023, EMODnet 2022b.

The quantified benefits of Fucus spp., considering the estimated habitat area and assimilation rates from literature, are estimated to be around 3195 tonnes of nitrogen, and 222 tonnes of phosphorus annually (Figure 29). No variability in the assimilation rates was provided by the utilized references.

The confidence in the general spatial pattern of this estimate is good. The ecosystem function is concentrated in shallow coastal waters. However, the growth rate data was not systematically assessed across latitudes within a single study increasing uncertainty. However, the confidence in the quantified estimate is low. First, estimates are not directly measured but calculated from growth rates, tissue nutrient content, and dry-weight to wet-weight ratios. Additionally, the growth rate data is based on only two points interpolated across the whole Baltic Sea.

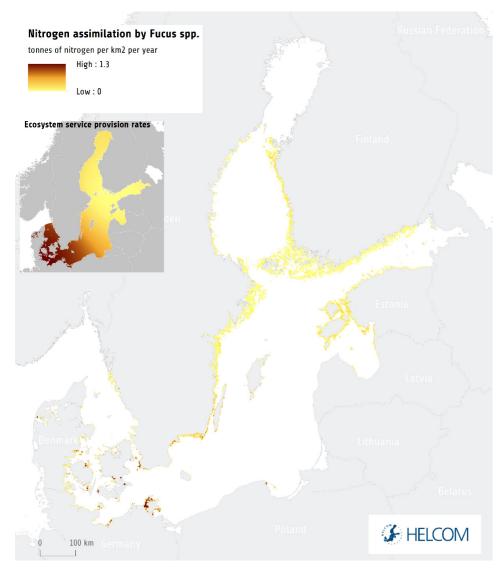


Figure 29. Map showing the spatial assessment of nitrogen assimilation by Fucus spp. in the Baltic Sea. The values are presented in tonnes of carbon per km². The smaller map in the upper left corner illustrates the ecosystem service provision rates, which were generated by interpolating data from Balina et αl. (2015). The distribution map was produced using data from HELCOM 2023, EMODnet 2022b, Torn et al. 2006.

2. Nitrogen and phosphorus storage

The roots and rhizomes of vegetated coastal ecosystems extend into the sediment of the seafloor and are used to store and absorb nutrients. Benefits of the nutrient storage ES were assessed with respect to provision of this ES by eelgrass and Fucus spp.

The quantified benefits of eelgrass, considering the estimated habitat area and storage rates from literature, are estimated to be around 422216 tonnes of nitrogen and 42221 tonnes of phosphorus in total. Provision of this ES is heterogenous in the Baltic Sea, ranging from 22 to 108 tonnes of nitrogen, and 2 to 11 tonnes of phosphorus per km² per year, with higher rates found in the Danish straits (Figure 29).

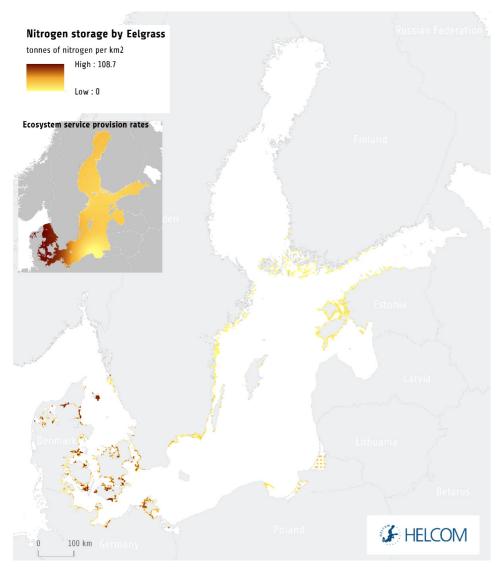


Figure 30. Map showing the spatial assessment of nitrogen storage by eelgrass in the Baltic Sea. The values are presented in tonnes of nitrogen per km². The smaller map in the upper left corner illustrates the ecosystem service provision rates, which were generated by interpolating data from various scientific sources (Röhr et al. 2016, Jankowska et al. 2016, Dahl et al. 2016). The distribution map was produced using data from HELCOM 2023, EMODnet 2022b.

The confidence in the general spatial pattern of this estimate is high. However, confidence in the quantified estimate is low. Interpolation was used to generate the whole Baltic Sea rate map and the eelgrass habitat quantity is uncertain.

The quantified benefits of Fucus spp., considering the estimated habitat area and storage rates from literature, are estimated to be around 1846 tonnes of nitrogen and 128 tonnes of phosphorus in total. Provision of this ES is heterogenous in the Baltic Sea, ranging from 0.20 to 1.3 tonnes of nitrogen and 0.01 to 0.09 tonnes of phosphorus per km² per year in the Baltic Sea (Figure 31).

The confidence is low in this estimate since it relies on data from a single study and single rate, which may not be representative of the entire Baltic Sea and does not capture any natural variation.

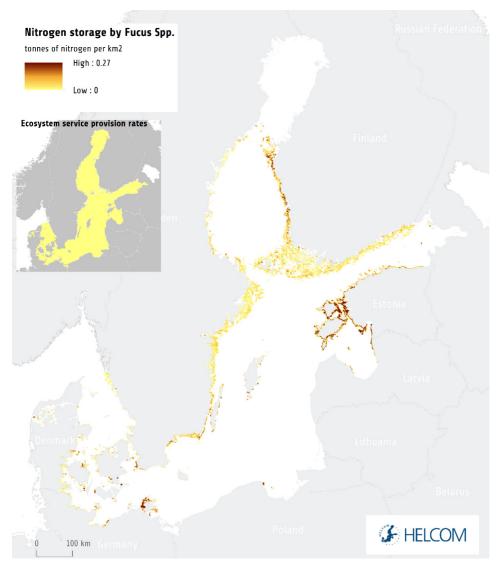


Figure 31. Map showing the spatial assessment of nitrogen storage by Fucus spp. in the Baltic Sea. The values are presented in tonnes of nitrogen per km² per year. The smaller map in the upper left corner illustrates the ecosystem service provision rates, which were generated by interpolating data from Balina *et al.* (2015). The distribution map was produced using data from HELCOM 2023, EMODnet 2022b, Torn *et al.* 2006.

3. Nitrogen and phosphorus sequestration

Soft-bottom sediments play a key role in nutrient sequestration, as they provide a place for excess nutrients to be buried and removed from the water column. Nutrient burial occurs in the sediments, where particulate nitrogen and phosphorus are covered by more recently deposited particulate matter and thus leave the ecosystem for the geosphere. This process helps to reduce the amount of nutrients available for the growth of harmful algal blooms. Another key process is denitrification, where bacteria convert nitrogen into a form that is not readily available for use by most plants and algae. During denitrification, nitrogen is converted into a gas, such as nitrogen gas or nitrous oxide, which is then released into the atmosphere (Deutsch *et al.* 2010). In addition, the process of anammox (anaerobic ammonium oxidation) also occurs in soft-bottom sediments, where specialized bacteria convert ammonium and nitrite to N2 gas, contributing to nitrogen removal from the marine environment

(Thamdrup and Dalsgaard 2002). These processes help to remove excess nitrogen from the marine environment, improving the health of the ecosystem. There are several studies that have analysed denitrification and burial of nutrients by sediments in the Baltic Sea (Deutsch *et al.* 2010, Jäntti, 2012, Bonaglia *et al.*, 2017, Lønborg, C., and Markager, S. 2021). Benefits of the phosphorus and nitrogen sequestration ES (including burial and denitrification) were assessed with respect to provision of this ES in soft-bottom sediments.

The quantified benefits of nitrogen sequestration in soft-bottom sediments, considering the estimated sediment type area and sequestration rates from literature, are estimated to be around 837809 tonnes of nitrogen sequestered annually. The soft bottom sediments bury 473268 tonnes of nitrogen and denitrify 364541 tonnes of nitrogen annually (Figure 32 and 33). Provision of the nitrogen sequestration ES is heterogenous in the Baltic Sea, ranging from 0.6 to 3.3 tonnes of nitrogen burial and 0.5 to 2.5 tonnes of denitrification

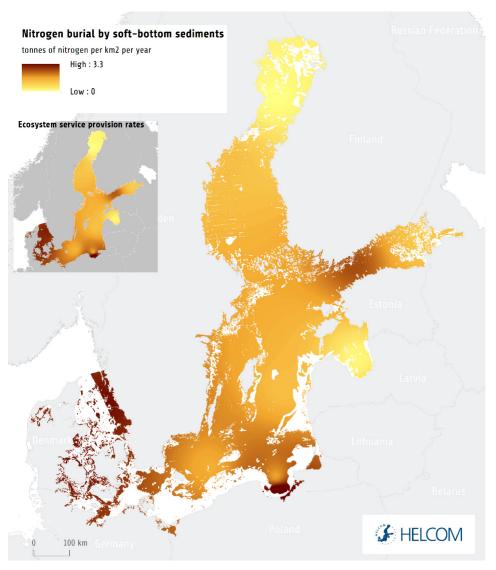


Figure 32. Map showing the spatial assessment of nitrogen burial in soft-bottom sediments in the Baltic Sea. The values are presented in tonnes of nitrogen per km² per year. The smaller map in the upper left corner illustrates the ecosystem service provision rates, which were generated by interpolating data from Lønborg and Markager (2021). The distribution map was produced using data from HELCOM 2023.

per km² per year, with higher rates in the south. According to Lønborg and Markager (2021), total nitrogen level in sediments started to decrease in the early 2000's in the Baltic Sea. The declines in total sediment nitrogen were only generally evident in the nearshore areas directly impacted by rivers. This is likely because total sediment nitrogen levels in these areas are more directly affected by river inputs, while further offshore, atmospheric and nitrogen fixation make up a larger proportion of the sources of nitrogen.

Confidence is moderate for the nitrogen and phosphorus sequestration in soft-bottom sediments due to several factors. First, mud and mixed areas were treated equally in this estimation, which does not accurately reflect the true distribution pattern of nitrogen and phosphorus sequestration in these areas. Additionally, the calculation of ecosystem benefit provision rates was performed based on literature for mud sediments, which will cause an over-estimation of carbon sequestration in this assessment. Several sources were used for nitrogen burial, and

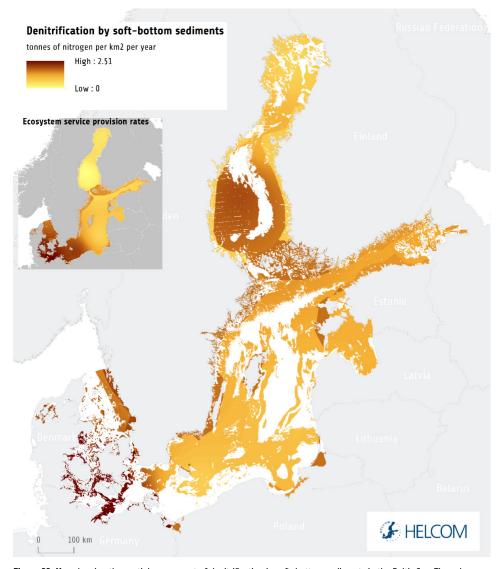


Figure 33. Map showing the spatial assessment of denitrification in soft-bottom sediments in the Baltic Sea. The values are presented in tonnes of nitrogen per km² per year. The smaller map in the upper left corner illustrates the ecosystem service provision rates, which were generated by interpolating data from various scientific sources (Deutsch et al. 2010, Jäntti 2012, Bonaglia et al. 2014, Lønborg and Markager 2021). The distribution map was produced using data from HELCOM 2023.

coastal and open-sea denitrification rates. The use of interpolation techniques and rate variability may introduce uncertainty or error into the estimates.

The quantified benefits of phosphorus sequestration in soft-bottom sediments, considering the estimated habitat area and sequestration rates from literature, are estimated to be around 248332 tonnes of phosphorus sequestered annually (Figure 34). Provision of the phosphorus sequestration ES is heterogenous in the Baltic Sea, with sequestration rates ranging from 0.21 to 2.21 tonnes per km² per year.

Confidence level is moderate for this ecosystem service. Mud and mixed areas were treated equally in this estimate as in phosphorus burial ES. High resolution spatial data modelled by Asmala *et al.* (2017) was used for phosphorus burial rates for most of the Baltic Sea. However, rates for Bothnian bay and Kattegat were interpolated from the Asmala data to produce a complete map of the spatial distribution in the Baltic Sea.

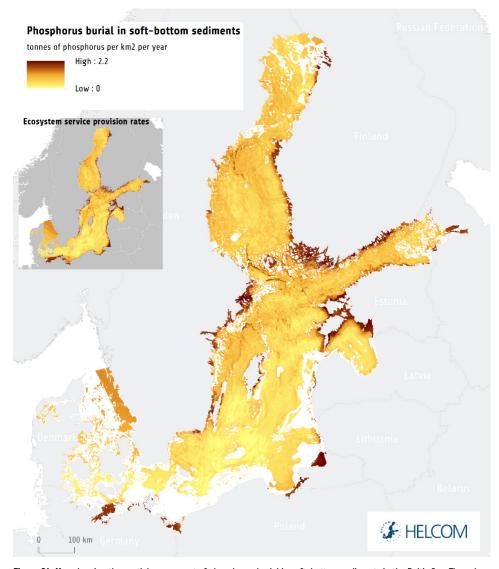


Figure 34. Map showing the spatial assessment of phosphorus burial in soft-bottom sediments in the Baltic Sea. The values are presented in tonnes of nitrogen per km² per year. The smaller map in the upper left corner illustrates the ecosystem service provision rates, which were generated by interpolating data from Asmala *et al.* (2017). The distribution map was produced using data from HELCOM 2023.

Table 22. Monetary benefits of the ES RM1 "Nutrient regulation" for nutrient sequestration provided by soft bottom sediments in the Baltic Sea. The colour denotes confidence (moderate). Source: own calculation. ^a The interval is based on the minimum and maximum sequestration rates (tonnes/km²).

	million €/year	€/km²/yearª
Nitrogen (Ntot) sequestration (includes burial and denitrification)	5 446	17 266 (7 345 – 37 830)
Phosphorus (Ptot) sequestration	4 9 6 7	15 711 (4 200 – 44 200)

The well-being impacts of the nutrient sequestration in soft bottom sediments are estimated in monetary terms, based on avoided costs for nutrient treatment from human activities. The estimate is based on costs of nutrient treatment by wastewater treatment plants (Hautakangas et al., 2014). However, the estimates may still be considered conservative, provided that results in Hautakangas et al. (2014) imply that additional and more costly measures than wastewater treatment would be needed to meet the nutrient emission targets of the Baltic Sea Action Plan. Using a unit cost of 6.5 € per kilogram for nitrogen and 20 € per kilogram for phosphorus (in 2021 prices) and the total sequestered amounts of nitrogen and phosphorus in the Baltic Sea region (tonnes/year), the total estimated monetary benefits for the Baltic Sea countries are 5446 million euros for nitrogen and 4967 million euros for phosphorus sequestration on average per year (Table 22). Confidence in the estimates is moderate, since they are based on an average unit cost for all Baltic Sea countries, but in reality, the costs differ depending on various factors (like size of a wastewater treatment plant, the nutrient reduction level).

5.2.3 Cultural Ecosystem Services

Assessment of the marine ecosystem components contributing to the provision of cultural ecosystem services (CES), is not available for the sea region. However, recent studies within the Baltic Sea illustrate various approaches and outcomes which can be applied at a regional scale in the future. Data on benefits of the CES is available for a monetary assessment of CES related to coastal and marine recreation, as well as a quantitative assessment of importance of benefits from all CES, including existence of habitats and species.

Link between the marine environment and CES

For the coastlines of Estonia, Latvia and southeast Finland, the MAREA project (http://marea.balticseaportal.net/) produced a coastal suitability index to spatially represent the suitability for different recreational activities (Box 2) (Forsblom *et al.*, 2022). Their model considered a variety of environmental factors that influence the suitability, such as wind speed and water depth. The work of MAREA is a valuable advance in the consideration and mapping of CES at a large scale.

In Latvia, AKTiiVS (2022) conducted an assessment on the contribution of relevant components of the marine environment to deriving benefits from CES. Data from a national survey were used to identify the relative importance of the components based on societal preferences (Box 3). The results reveal that around 50% of the contribution can be attributed to various biotic components of the marine ecosystem, which are directly impacted by environmental degradation (marine plants and species, regulating ecosystem services). This work highlights the vulnerability of CES to degradation of the Baltic Sea.



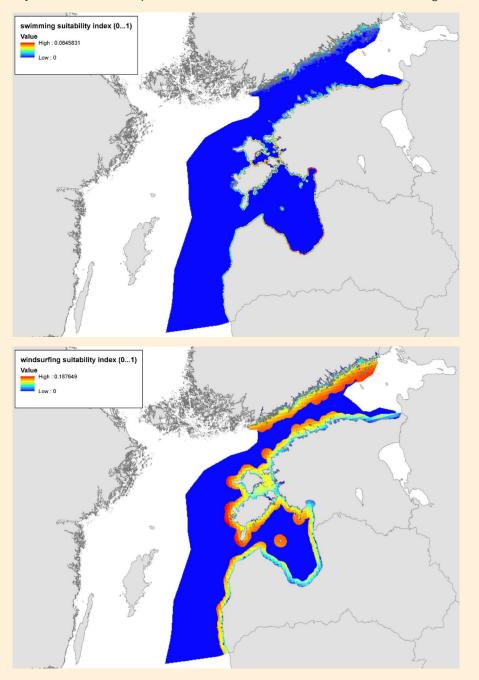


Mapping suitability of coastlines for practising different recreational activities in Estonia, Latvia and Finland.

A study conducted in the frame of Central Baltic Programme 2014-2020 project "From marine ecosystem accounting to integrated governance for sustainable planning of marine and coastal areas" (MAREA). Information from Forsblom *et al.* 2022.

The study developed an index that summarizes the features that make coastal areas suitable for the development of cultural and recreational activities. Relevant data layers were combined to produce a coastal

suitability index to spatially represent the suitability of Estonian, Latvian and Finnish coastlines for practising different recreational activities (kitesurfing, windsurfing, sea-kayaking, swimming, snorkelling, sunbathing). Data layers were used both for defining ideal spatial and temporal frames for practising different recreational activities and calculating the suitability index for each activity. The produced maps (examples are provided below) show the potential of these services in terms of environmental variability (taking into account such environmental variables as wind speed, bottom sediment characteristics, depth, water temperature, daylight hours, distance from the shore) and do not necessarily reflect people's preferences. Preferences are a product of multiple factors, like natural conditions, infrastructure, cultural background, which were not taken into account in this modelling exercise.





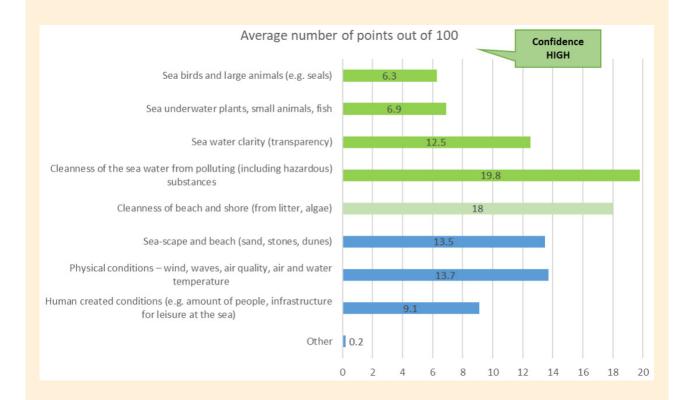
Relative importance of the marine environment characteristics for deriving benefits from cultural ES in Latvia.

Information from AKTiiVS (2022) Socio-economic assessment of marine ecosystem services. Report of the project "Improving knowledge on the state of the marine environment" (No 17-00-F06803-000001).

As part of a national survey in Latvia in 2021 data were collected to assess relative importance of relevant marine

characteristics for deriving the benefits from CES, covering all such ES. Respondents were asked to allocate 100 points among the listed characteristics according to their importance for deriving the benefits of the CES. The results reveal that around 50% of the contribution can be attributed to the biotic characteristics of the marine ecosystem (linked to marine plants and species, regulating ecosystem services).

The figure below shows the relative importance of the characteristics of the marine environment for deriving benefits of cultural ES according to preferences of the Latvian citizens. (Source: AKTiiVS (2022).) The biotic marine ecosystem characteristics are indicated with green colour bars. The data have been collected from a national survey implemented in 2021 with representative sample. Confidence in the data is high.



Cultural ecosystem services related to recreation (C1-C6)

Estimates for the monetary benefits of CES related to recreation for all the Baltic Sea countries were calculated based on literature and benefit transfer (see chapter 4). The estimates for Germany, Finland and Latvia were taken from a study, where data have been collected from surveys in these countries (Bertram *et al.* 2020; Ahtiainen *et al.* 2022). Table 23 contains relevant data from this study, including the used values of 'consumer surplus' (CS) per person. Estimates for the remaining countries relied on benefit transfer.

The calculated total benefits for the Baltic Sea countries (Table 24) are in the range of 34 billion euros per year. Comparing this estimate with the similar estimate for HOLAS II (HELCOM, 2018; Cza-

jkowski *et al.*, 2015), which was based on data collected in 2010 covering all the Baltic Sea countries, the benefits are more than two times higher. However, it can still be judged as a conservative estimate, taking into account the developments and changes in the sea use since the survey in 2010.

The developed estimate covers various CES, and the monetary estimation approach does not allow estimating the benefits of individual CES. It can be assumed that the estimate covers C1-C6, however benefits of some CES might be covered only partly by such an estimation approach (for instance, C3 Environment for science and education, C4 Environment for maintenance of cultural and historical heritage).

Table 23. Data on recreational benefits used for monetary estimation of the benefits of CES related to recreation. The colour denotes confidence (good). ^a From Ahtiainen at al. (2022). ^b From Bertram *et al.* (2020).

	Consumer surplus € per leisure visit [95% CI] ^a	No of leisure visits per year (SD) ^b		Share of visitors in total population ^b	Consumer surplus € per person per year (in 2017 prices)
Germany	83.3 [74.2; 92.4]	4.3 (1.0)	358	0.49	176
Finland	79.5 [66.2; 92.9]	10 (3.0)	795	0.76	604
Latvia	66.9 [42.9; 91.0]	4.8 (1.5)	321	0.79	254

Table 24. Monetary benefits of CES related to recreation in the Baltic Sea region. The colour denotes confidence (orange for moderate-low and blue for good). Sources: own calculations, World Bank (2022a). The asterisk marks the study countries from which the values are transferred to other countries. The CS from Finland is transferred to Denmark and Sweden, the CS from Latvia to Estonia, Lithuania, Poland and Russia. ^a Adult population (estimated to be 75% of the total population; data of World Bank (for 2020) for the total population). ^bThe Baltic Sea coastal population is assumed to be 5% of the total population of Russia.

	Total population ^a	Consumer surplus € per person per year (in 2020 prices)	Total benefits million € per year
Denmark	4 373 553	735	3 2 1 5
Estonia	997 109	319	318
Finland*	4 147 157	619	2 567
Germany*	62 370 653	182	11 351
Latvia*	1 425 337	268	382
Lithuania	2 096 164	333	698
Poland	28 424 303	297	8 442
Russia ^b	5 403 903	267	1443
Sweden	7 765 082	686	5 327
Total			33 743



C7 Existence of marine habitats and species

This CES aims to cover the non-use value of marine habitats and species gained from their existence and preservation for future generations, independent from any current or future use of the ecosystem. There are monetary valuation approaches that allow measuring marginal changes in these benefits, but not the total benefits as such. Therefore, other socio-economic data are used for illustrating the socio-economic benefits from this CES.

Figure 35 provides data on relative importance of C7 compared to other CES. The data come from three Baltic Sea countries, representing diversity of socio-ecological contexts in the sea region. The data have been obtained from national surveys in each country conducted in 2016-2017, based on representative national samples (Ahtiainen et al. 2019). The results reveal that the importance of the existence of marine habitats and species is assessed by Germans and Finns as high as the importance of the recreational and aesthetic experiences, while the importance of the existence value is lower in Latvia (11 points on average out of 100). More recent data for Latvia (AKTiiVS 2022) indicates changes in the societal preferences towards higher importance of the existence value (13 points in 2021).

While the recreational benefits are estimated to be in range of 34 billion euros per year, these results suggest that the existence of marine habitats and species also brings considerable benefits to human well-being.

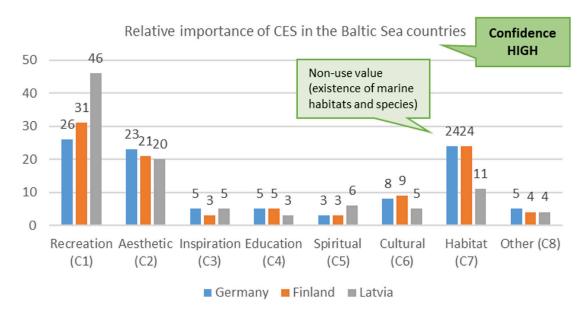


Figure 35. Relative importance of the CES (average points out of 100 allocated to each CES) for the Baltic Sea countries – Germany, Finland, Latvia. The data have been collected from national surveys with representative samples, implemented in 2016-2017. Confidence in the data is high, as these data are derived directly from national representative surveys. Source: Ahtiainen et al. (2019).

5.2.4 Aggregated ecosystem service potential map

An aggregated ecosystem service potential map was created using the Ecosystem Service tool extension to the Baltic Sea Impact Index calculation tool developed by the Pan Baltic Scope project (http://www.panbalticscope.eu/) (Ruskule *et al.* 2023). This updated evaluation performed the mapping exercise utilizing 54 different ecosystem component layers, including benthic habitats, pelagic species, habitat-building species, mobile species, and their key habitats (Figure 36). The tool aggregates the binary assessment of the contribution to the provision of a particular ecosystem service for each ecosystem component (0 – the ecosystem component has no or negligible contribution to the particular

service; 1 – the ecosystem component can provide the service).

It is important to note that the aggregated marine ecosystem service map has low confidence because the ES tool only considers the presence or absence of ecosystem components to produce the map. This means that there is potential for double counting since the distribution maps of the ecosystem components may overlap. Additionally, it is difficult to demonstrate low and high levels of ecosystem service provision since the provision from each ecosystem component was considered equal. This lack of granularity in the data makes it difficult to have confidence in the accuracy of the map. Note that this exercise does not cover all ecosystem components or ecosystem services in the Baltic Sea.

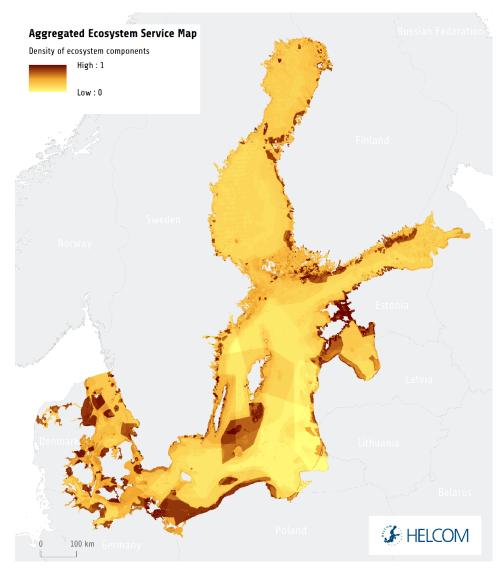


Figure 36. Aggregated ecosystem service potential map combining 54 different ecosystem component layers sourced from the HELCOM Map and Data Service (HELCOM 2022). Updated HOLAS 3 ecosystem component data layers were used in the tool application. Map demonstrates the density of ecosystem service potential in the Baltic Sea.

5.2.5 Other ecosystem service evaluations

The ecosystem service concept can also be applied to better understand how society perceives the values provided by nature. Two data sets from Latvia illustrate the proportion of the national population that benefits from the marine ES and the relative value the population assigns to benefits of the various ES.

The assessment of the population benefiting from all relevant marine ES is based on data from a Latvian national survey implemented in 2019 (Figure 37) (AKTiiVS, 2022). Respondents were asked to assess the importance of benefits from individual ES, and the results have been used to estimate the benefiting population (as percentage share of the total population).

The results reveal that the regulating ES are the most highly assessed group of the ES overall, where the benefiting population is estimated to be 87% for nutrient regulation, 94% for hazardous substances regulation and 95% for carbon sequestration, respectively. The benefits from recreational and aesthetic experiences were assessed as important by 92% and 91% of respondents respectively, and this share is higher than the regular users of the sea for recreation (84% of the national population based on data from the same survey). This result indicates that these ES also have non-use value

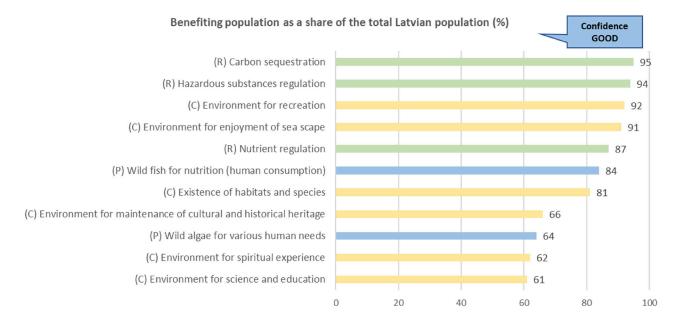


Figure 37. Illustration on the benefiting population for various marine ecosystem services based on data from Latvia (AKTiiVS 2022). The benefiting population is estimated as a share of the total national population (%). The data have been collected from a national survey implemented in 2019 with representative sample. The colours denote ES of different groups – provisioning (blue), regulating (green) and cultural (yellow) ES. Confidence in the estimates is good, as they are based on data derived directly from a national representative survey.

(option use and/or bequest value). Also worth noting is the considerable share of the population benefiting from the existence of marine habitats and species -81% of the total population.

Figure 38 provides an illustration on relative importance of the ES benefits from the same Latvian national survey (AKTiiVS 2022). Respondents were asked to distribute 100 points among the benefits of marine ES according to their importance. Such data can complement monetary estimates of the benefits of ES, for instance by indicating underestimated ES or the potential magnitude of the benefits of ES, which have not been monetised.

The results reveal that one third of the points (33 points) were allocated to the benefits of provisioning ES (wild fish and algae for various human needs) and only 24 points to the benefits of cultural ES, with considerable importance of the benefits from existence of marine habitats and species (8 points out of 100). The highest importance is allocated overall to the benefits of regulating ES (carbon sequestration, hazardous substances regulation and nutrient regulation) with 43 points out of 100 in total. These results suggest that the benefits of regulating ES are higher than monetised in the current sea region ES assessment, in particular for carbon sequestration. The results also indicate that benefits from hazardous substances regulation ES, which are not included in the sea region ES assessment, could be at least as high as the estimated monetary benefits of nutrient regulation ES. It should be noted however, that such conclusions have moderate confidence, as they are based on data from a single Baltic Sea country.

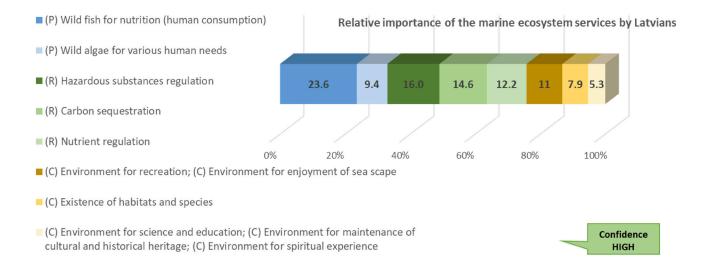


Figure 38. Illustration on relative importance of benefits from the marine ecosystem services (average points out of 100 allocated to the benefits of each ecosystem service) based on the assessment of Latvian citizens (AKTiiVS 2022). The data have been collected from a national survey implemented in 2019 with representative population sample. Confidence in the data is high.





5.3. Changes over time for ecosystem services

This is the first assessment of ecosystem services included in a HO-LAS assessment, so no previous data exist.



5.4. Relationship of ecosystem services to drivers and pressures/biodiversity

The ES approach is seen as a way to assess interactions between ecosystems and human well-being, where biodiversity plays a key role in the ES provision. Negative impacts on the marine biodiversity created by the pressures affects the human well-being by changes in the ES supply (Bryhn et al. 2020). The developed ES assessment is not yet able to demonstrate the well-being changes due to the degraded state of the marine biodiversity or the benefits of improving the state. However, it already can demonstrate the considerable benefits to citizens of the Baltic Sea countries from the ES provided by the marine ecosystem.

The results of this assessment are linked to the economic and social analysis of the use of marine waters (Section 3) and other thematic assessments, such as the <u>Thematic Assessment of Spatial Distribution of Pressures</u> and Impacts and <u>Thematic Assessment of Biodiversity</u>. The ES approach has potential to be used for the costs of degradation analysis and the assessment of benefits of implementing measures and improving the state.



5.5. How was the assessment of ecosystem services carried out?

Ecosystem service supply estimates cover provisioning and regulating ES. For the regulating ES the estimates were developed for individual marine habitats, ensuring clear and quantified link with the ecosystem components (for instance, phosphorus amount sequestered by soft bottom sediments). The ES supply rates were developed based on existing scientific literature for the Baltic Sea, and these rates are combined with spatial data on the habitat distribution to provide spatial and quantified estimates on the ES benefits. For the provisioning ES ICES and STECF data are used for the volume of catch and marine aquaculture production in the Baltic Sea. Detailed information on the used data and estimation approaches is provided in Annex 1.

Estimates of the socio-economic values of the ES have been developed as part of HELCOM BLUES project. For the provisioning and regulating ES they build on the quantitative benefit estimates, en-

suring further link from ecosystem components to human well-being. The socio-economic estimates are based on indicators, which have been defined based on literature and taking into account data availability for their application. For the value indicators the assessment focuses on providing monetary estimates. However other quantitative indicators have also been developed, which aim to analyse human preferences towards ES in non-monetary terms, allowing broader assessment of the human well-being aspects. Such indicators, in most cases, require special data collection (surveys), and no uniform data are available for all the sea region countries. Therefore, only country-scale illustrations could be provided based on available data.

The most appropriate monetary (welfare) measure is 'economic value', measured by 'consumer surplus' or willingness to pay for the environmental good. Since special valuation studies are necessary to estimate the 'economic value', such data are generally not available, in particular for the whole sea region. Hence, other measurements, like market prices and avoided costs, have been used. It needs to be noted however that these other metrics are only proxies for the 'economic value' and allow measuring socio-economic impacts, but not the 'economic value'. The monetary indicators of the various ES are based on different assessment methods - market prices for provisioning ES, cost-based methods for regulating ES, a travel cost method for cultural ES related to recreation. EUMOFAP data have been used for the market prices of various fish and aquaculture products. Unit values (€/kg of nitrogen, phosphorus, carbon dioxide) have been developed for the regulating ES based on scientific literature, and they are multiplied by the quantitative benefit estimates (tonnes/year) to calculate the total monetary benefits for the Baltic Sea countries. Data for the cultural ES come from existing studies, based on national surveys in the Baltic Sea countries. The monetary estimates related to recreation come from a study, covering three Baltic Sea countries, and a value transfer has been used to estimate the benefits for other countries. Detailed information on the used data and estimation approaches is provided in Annex 1.



5.6. Follow up and needs for the future with regards to ecosystem services assessment

The updated HELCOM Baltic Sea Action Plan (HELCOM 2021) includes actions on integrating the economic and social analyses into HELCOM work strands to allow for assessment of the linkages between the marine environment and human wellbeing (HT15), developing and applying regionally coordinated methods in support of analyses of ES (HT18), and on improving the use of results from economic and social analyses in decision-making (HT16).

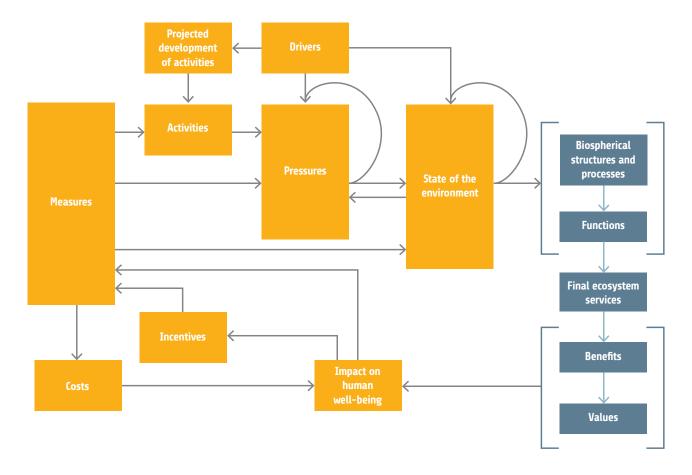


Figure 39. Conceptual framework, based on DAPSIM framework and including the ES cascade model, for assessing well-being impacts of policies for protecting and sustainable use of the marine environment. (Source: HELCOM BLUES). The green colour denotes elements of the ES cascade.

These actions are closely supported by work on a conceptual framework for economic and social analyses developed by the ACTION and BLUES projects (Figure 39). The ES portion of this framework builds on the concept of the ES cascade model, which was developed to explain how the notion of ecosystem services can be used to understand the relationships between people and nature (Potschin & Haines-Young 2016a). The cascade model is an expression of the key components of the ES paradigm, which scrutinise the distinction between what are understood as 'services' and 'benefits', and to examine the particular 'functional' characteristics of ecosystems that give rise to services, as opposed to the more general ecological structures and processes that support them.

The current information and knowledge base for the sea region is not yet sufficient for fully implementing this framework to assess the well-being impacts of policies. It would require assessing changes in the ecosystem in sea use and/or policy scenarios and resulting changes in the ES supply. These changes can then be assessed in terms of the impacts on human well-being, based on changes in the ES benefits and values. However, significant advancement has been made to develop linkages between the assessment elements and quantitative and monetary estimates for the ES elements of the framework.

The developed assessment provides advancement towards quantified assessment of the link between the ecosystem and human well-being. However, many methodological and information gaps remain to make such assessment as a policy support tool. There is a need to further develop quantitative estimates on the ES supply to cover all relevant ecosystem components, as well as approaches and estimates for linking the ecosystem components to the supply of provisioning and cultural ES. Quantified linkages are needed for assessing changes in the ES supply and socio-economic values in the sea use and policy scenarios

With regards to the socio-economic assessments, the needs for the future work relate to further development of the socio-economic ES assessment methods and information base, as well as analytical capacity for policy scenario and trade-off analysis.

As demonstrated by the current assessment, the socio-economic ES estimates are based on various valuation methods, providing different estimates for individual ES (market value, avoided costs, consumer surplus). This situation is largely determined by information availability. However, improvements in the methods need to be explored to guide the future research and data collection efforts. In addition, specific methodological issues need to be addressed, for instance, aggregating socio-economic estimates for various ES, spatial and trade-off analysis of the ES benefits and values. Also, more advanced approaches for assessing uncertainties need to be considered.

Confidence assessment of the developed estimates indicates rather high uncertainties – the confidence has been assessed as moderate for the majority of the sea region estimates. The main reason is the lack of consistent data from the countries. The assessment needs diverse data, which in most cases come from specially conducted national surveys. International research projects form an important source of consistent data. But national studies also can advance the methodological and information base for the sea region assessment. Further efforts should be targeted to developing quantitative and monetary approaches and estimates, including for the ES, which are not covered by the current assessment (in particular, the hazardous substances regulation). Further work on the sea region scale should include specifying the data needs, promoting the data collections and supporting reviews and synthesis of the information base.

In order to support the policy making in relation to the protection and management of the marine environment, there is a need to analyse the socio-economic implications of environmental protection and sea use policy scenarios. The changes in the ecosystem created by scenarios can be assessed in terms of changes in the ES supply. The socio-economic assessment is needed to assess the impacts of these changes on human well-being. Such a complex assessment needs information and analytical tools, which are currently missing in particular for the socio-economic analysis. Development of such tools is an important future work to improve the analytical capacity for the policy scenario and trade-off analysis.



Future tools - ecosystem accounting

Marine ecosystems provide a wide range of goods and services ('ecosystem services') that support human activities, and by extension the livelihoods of communities. This is especially true across the Baltic, where the Baltic Sea supports sectors such as fishing, shipping, ports, and related infrastructure. These activities depend on ecosystems, which could be considered the natural wealth (or 'capital') of member states. Framing marine ecosystems lends to the use of accounting frameworks, which could be used to trace the relationships and dependencies from marine ecosystems to society and the economy.

Ecosystem accounting is a structured compilation of consistent and comparable information on ecosystems and ecosystem services in the framework of national accounting, such as spatial data, statistics and indicators. As a way of organising stocks and flows within the environment, it is aligned with existing statistical standards that measure society and the economy. It uses environmental data as a foundation to relate flows from the environment (ecosystem goods and services) to social circumstances (or values) and economic activity. Using the resulting ecosystem service benefit estimates and monetary valuations, ecosystem accounting can provide an additional perspective for linking flows within a socio-ecological system (complex flows and feedbacks between environment, society, and the economy).

Future work should focus on the framework provided by UN SEEA EA, and apply the following five steps in the Baltic Sea marine ecosystem accounting process:

- Identification of priority policy needs and available
 data
- Preparation of ecosystem extent accounts: Spatial distribution of ecosystem components (assets) and how it changes over time. That activity includes preparation of a broad data inventory for ecosystem assets,
- Preparation of ecosystem condition accounts: Assessing quality of the Baltic Sea ecosystem and its assets using several variables (e.g., ecosystem functions) and indicators (e.g., HELCOM Core Indicators),
- 4. Preparation of physical ecosystem services accounts,
- Preparation of monetary ecosystem service and ecosystem asset accounts.

Outcomes of the HOLAS 3 ES assessment can be utilized in steps 1, 2, 4 and 5. However, it is important to note the lack of critical data on the change in ecosystem components over time and the condition of these components. These data gaps must be addressed to take full advantage of ecosystem accounting in the Baltic Sea.



Results for the cost-benefit analysis



Assessment results in short

- This chapter reviews the methodology and state-of-the-art of regional cost-benefit analyses (CBA). It also assesses the legal and political status of CBA in Baltic Sea protection, and the critical components of utilizing the method, particularly information on costs and benefits. Finally, the chapter explores how much decision makers can rely on environmental CBAs for various topics of Baltic Sea protection based on the currently available information.
- Generally, in emerging environmental problems such as marine litter, decision makers should understand the uncertainty of the CBA and put emphasis on the precautionary principle. In emerging problems both the actions to mitigate the problems as well as the severity of the environmental risk are still poorly known. Obtaining more detailed information is costly and time consuming. Hence, decision making should be guided by the CBA but not rely on it. We also show that with more thoroughly understood problems, CBA offers a transparent and effective way of analysing the policy alternatives.



6.1. Introduction to cost-benefit analysis

Cost-benefit analysis (CBA) is a method tailored to evaluate public projects with the intention of helping decision-making and policy outcomes (Nas 2016) (Zerbe & Farrow 2013). The idea behind CBA is to identify all potential costs and benefits from a project, monetize and compare them to understand whether the project is worth implementing (Nas 2016). If benefits exceed the costs, society is better off when the project is implemented, while the opposite is true if costs exceed benefits (Hanley et al. 2009).

CBA differs from traditional financial analysis by focusing on a societal perspective (Nas 2016). While in financial analysis unintended external effects are typically ignored, it is the explicit goal of a CBA to address and quantify changes in the provision of public goods and the impact of unintended effects. While CBA is a useful tool, it is not a substitute for democratic decision-making (Zerbe & Farrow 2013).

6.1.1 Steps of a CBA

Figure 40 describes how CBA is typically conducted, illustrating the various steps necessary for a specific policy, in this case achieving (or not) Good Environmental Status (GES) of marine waters.

The first step is to clearly define the problem the CBA will investigate (DeRus 2010). Relatedly, the relevant (and feasible) alternatives to be analysed should be identified. These can either include policies or projects, that either are under consideration or have already been implemented (OECD 2018). A minimum of two alternatives should always be present in a CBA, but additional alternatives can be included. In the case illustrated in Figure 40, the alternatives are either achieving or not achieving GES.

At the second step, the CBA defines which parts of society will be affected by the change in policy. Different alternatives will impact individuals in a society differently: with distinct regional, national and even international impacts (DeRus 2010).

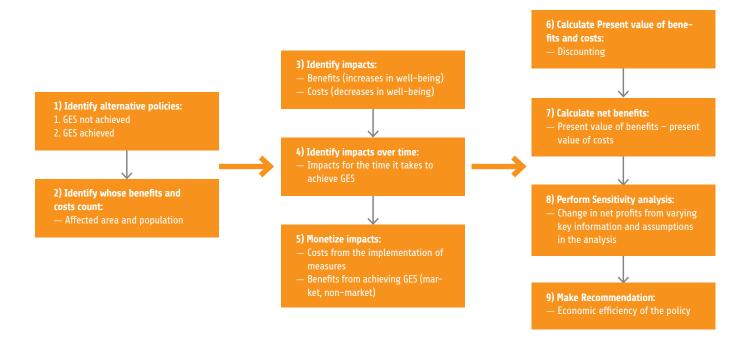


Figure 40. Steps for conducting a CBA for achieving Good Environmental Status (GES) of marine waters. Adapted from various CBA manuals including OECD (2018), Nas (2016), DeRus (2010) and Hanley and Barbier (2009).

At the third stage, the costs and benefits of implementing each alternative are reviewed (DeRus 2010). In many cases, one alternative is simply not implementing a certain action. Benefits include any increases in human well-being, while costs should cover any decreases in human well-being. This is where CBA deviates from a traditional financial analysis, considering not only costs and benefits with an immediate market price, but also adding non-market costs and benefits.

At the fourth step, the analysis considers how benefits and costs are likely to be incurred over time. While some costs and benefits only occur once, others can last for long periods of time or even infinitely (DeRus 2010). For the case of achieving GES, impacts should be accounted for until GES is achieved.

The fifth step is what distinguishes CBA from other decision-making frameworks: all impacts (both costs and benefits) are expressed in monetary values by either using market prices or using shadow prices that reflect their marginal social cost or benefit (Hanley & Barbier 2009). While the price for some impacts is available from competitive markets, such as the costs of implementation of measures to achieve GES, other benefits do not have immediate value estimates, such as the benefits from achieving GES. Non-market values can be monetized using techniques like revealed or stated preferences (DeRus 2010).

The sixth step is to discount costs and benefits over time. Costs and benefits that occur in the present are more impactful than those that occur in the future based on empirical studies of human preferences. To compare benefits and costs over time one should convert them to present value terms by applying an annual discount rate (DeRus 2010) (Hanley & Barbier 2009). But, because the value of societal goods is different than market goods, CBA typically uses a smaller discount rate than those used in financial analyses to better reflect society's preferences (Nas 2016).

The discounted costs and benefits can then be summed to calculate the Net Benefits, also referred to as the net present value of the investment, which is the difference between the present value of benefits and present value of costs (Hanley & Barbier 2009). When the net benefits are positive (that is when benefits outweigh the costs), we say that the alternative will increase social welfare if implemented.

Finally, a recommendation can be made based on the calculated net benefits. The project should be implemented if the net benefits are positive. If more than two alternatives are considered, then the recommendation should be to recommend the alternative that yields the highest net benefits (Nas 2016). Sensitivity analyses may be performed on certain parameters. The goal of the sensitivity analysis is to determine the sensitivity of the net benefits to changes in key variables. Possible conclusions include either that the net benefits are stable with different parameter values, or that they change drastically. This is an important exercise to show how robust the conclusions of a CBA are.



6.2. Economic analyses in the Marine Strategy Framework Directive (MSFD) and implications for utilizing CBA

The Marine Strategy Framework Directive (MSFD) aims to reach and maintain good environmental status in the marine environment by 2020. The Directive is set up in a continuous six-year cycle which all EU Members States are required to follow (Figure 41). Many of the steps in this cycle require the use of economic analyses. The first step, the initial assessment, includes an economic and social analysis of the use of marine waters (Chapter 3) and of



Figure 41. Describing the 6-year cycle of the Marine strategy framework directive

the cost of degradation of the marine environment (Chapter 4), according to Article 8 of the Directive. These analyses cover data on economic sectors that use the marine waters such as fisheries, marine tourism and shipping, as well as an assessment of the cost of the environmental degradation caused by these uses. The cost of degradation is the welfare forgone by not being at GES, reflecting the reduction in the value of the ecosystem services provided.

The economic analyses in the initial assessment are descriptive in nature. However, other requirements for economic analyses in the Directive are meant to be used as direct support for decisions. In development of their Programme of Measures, each Member State should conduct a cost effectiveness analysis as well as impact assessments, including CBAs, prior to introducing new measures according to Article 13 of the Directive. Of all the different economic analyses required from the Directive, the CBA is the most intensive due to the amount and extent of data that is required to perform the analysis.

In its assessment of the Member States' Programmes of Measures 2016-2021 under Article 16, the European Commission remarked that the CBAs for new measures were often incomplete (EC 2018). In previous surveys Member States described many challengers in regard to performing the CBA, including, lack of data, limited understanding of cause effect relationships, which makes it difficult to quantify the environmental and social impacts of measures. Another challenge mentioned by various Member States is a lack of funds and/or time to perform the analyses (EC 2020).



6.3. Knowledge gaps and CBA - a schematic model

For environmental CBA, quantification of costs and benefits is difficult. For example, the CBA might be conducted to find whether it is worthwhile to undergo expensive abatement which, at the time of conducting the CBA, might be a poorly developed or even unknown process.

The role of uncertainty and value of information for environmental CBAs closely resembles CBA applications in health care. In both cases, there are two separate phases to making a decision: what choice to do based on current understanding, and whether to invest in costly research to improve the quality of information and reduce uncertainty (Koerkamp et al. 2006). Some choices are urgent and need to be taken immediately. However, increasing the certainty of the analysis increases the chance that the right choice is made and wrong one is avoided.

Literature on the value of information characterizes similar choices in standard economic settings. Obtaining better information is costly and valuable, if we wish to avoid uncertainty regarding future outcomes of our current decisions (Gollier 2001, pp 383-386). The value of more precise information is more often studied if there are direct economic stakes to consider. The concept applies to environmental decision making even though it is less often utilized in environmental economics literature (see, however Horan 2001). Fisheries is an example where decisions

on regulating economic activity (fishing intensity) have to be made based on uncertain information on the environment (status of fish stocks). The precision of the fish stock estimates can be improved with costs. The estimates are often generated using time-series data on landings or combining these with other types of data. Muradian et al. (2019) analyses how much each additional data type improves the precision of the stock estimates of Pacific herring in Prince William Sound, Alaska. Furthermore, they estimated the monetary value of the precision improvements which could be reflected against the costs of obtaining the additional data. As an example, their analysis indicated that disease surveys where most influential in both decreasing the probability of the wrong management decision (allow fishery when it should be closed; close down fishery when it could be allowed) and in terms of providing the highest monetary returns for the resources spent to the survey. They analysed a topic with a market-based economic activity on one side and environmental information on the other. The costs of profits foregone due to excessive restrictions or from allowing the stocks to collapse as well as from conducting the surveys are clearcut. Also, the particular fishery they consider has been systematically analysed for 50 years.

The setup changes as we move towards problems related to environmental quality without direct and substantial market-based benefit side, and as the problem itself gets more complex and less understood. In addition to being complex, tasks such as improving the overall water quality of the Baltic Sea, have a strong public good character. Markets do not provide public goods without incentives or mandates from the society. Consequently, markets do not provide data or understanding regarding their environmental or societal characteristics.

Whether to invest in oxygenation of the Baltic Sea as a eutrophication management measure is an example of an uncertain, poorly understood question with a strong public good character. Ahlvik and Iho (2018) analyse the problem by taking into account the uncertainty on ecological effects and thus on the benefits, and the fact that the effects of oxygenation on an open sea can only be detected if the investment is big enough to allow isolating the effect of the measure from natural variability. The costs of obtaining better information are thus embedded in the (environmental and financial) costs of conducting the very measure that is analysed. Their model highlights the problem of applying CBA

for environmental projects where acquiring more precise information about its effects is very difficult without implementing the project. Essentially, their model draws explicitly the limits of environmental CBA under uncertainty. CBA can support decision making up to a certain point after which the choices have to be made on political, sociological and/or ethical grounds.

Based on the existing approaches on the value of information we can derive a schematic model on environmental CBA. It depicts a world where decisions on certain environmental protection problems need to be taken under uncertainty regarding the costs and benefits of the alternatives. At the core of any environmental CBA is uncertainty arising from natural variation. It cannot be totally eliminated regardless of research efforts. That is, decision making always has to be done under some amount of uncertainty. However, uncertainty regarding the costs, effects, and economic benefits of the effects can be reduced by conducting more research. Research is time consuming and costly.

Consider an environmental project as presented in Figure 42. Each of the three pairs of bars depict the assessment of costs and benefits for this project. The difference between the pairs is the quality and precision of information that was available for the assessments. The first pair of bars on the left depicts the assessment results based on currently available information on potential societal benefits (orange bar on the left) and costs (yellow bar on the left) of the project. The ranges of the estimates are wide. There might be just a single study or a small number of studies with uncertain or contradicting results (for example the ecological conditions for isolating the geographical incidence of the benefits should be refined or the benefits are obtained using transfer functions). Whatever the reason, the outcome of the CBA with existing data is not informative for policy making: the costs seem to be as likely to be above or below the societal benefits of the project.

The middle pair of bars depicts cost-benefit assessments after putting effort into making the estimates more precise. Based on the characteristics of the environmental problem, supplemented monitoring programs and a firsthand economic valuation study might decrease the uncertainty of the benefits estimate. While closer collaboration with the technology provider might reduce the costs estimate uncertainty. The bars in the middle, however, indicate that we still do not know enough on the cost-benefit ratio to aid decision-making.

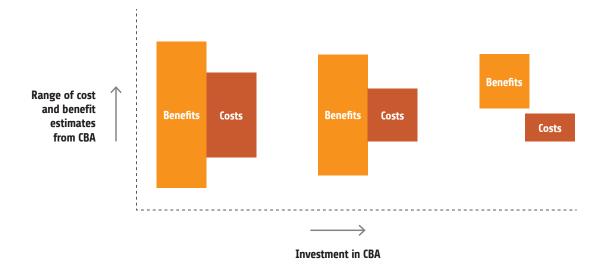


Figure 42. Schematic of a hypothetical CBA under different levels of investment

The pair of costs and benefits on the right denote the estimates after putting even more resources on increasing precision. Research on the economic spill over effects at the regional scale might have convinced the analysts that the true benefit value was found on the upper range of the previous benefit estimate range. A detailed spatial analysis of the costs which takes into account the heterogeneity of the area might move the costs to the lower end of the previous assessment range.

The key thing in Figure 42 and the discussion above is that it costs money and time to narrow down the cost and benefit estimates. Like health care, there are situations where decisions must be made despite knowing that the available data will not be precise enough to make an informative CBA. This is clearly the case with emerging pollutants: we do not know the harm they will eventually cause to us and to the Baltic Sea, and we do not know the technologies – and hence their costs and effects – to mitigate such pollutants.

The question to ask is, how much time and resources do we have to invest? There are no available answers to this question. The key thing is that from the characteristics of the problem at hand, we should be able to estimate how costly and time consuming it will be to improve the quality of information. This should be reflected against the scope of potential net benefits and against the schedule of the decision making. Generating a new environmental CBA study on a topic where the scientific fundaments are well known takes at least a year, from gathering the necessary ecological information, generating the survey in cooperation with the ecologists, piloting it with a small group of respondents, sending it out, collecting the answers and analysing and reporting the results. A recent example could be the survey on Finnish citizens attitudes towards hydropower and river ecology. It was initiated within the SUSHYDRO-project in December 2021 and the report was published in October 2022 (Artell et al. 2022). The situation changes, however, if the scientific information needed for the survey is still underdeveloped or very uncertain. This would be the case with marine litter. We could, of course, ask respondents to evaluate different alternatives and their willingness to pay for them. The answers, however, would change dramatically if it turned out the microplastics were a) totally harmless for humans b) causing deadly diseases after certain cumulative exposure to them. That is, improving the precision of environmental CBA may hinge on advances of natural science. There are no methodological shortcuts telling us the economic value of environmental changes before we know what the environmental changes mean to our biological wellbeing.

There are also well-established topics which might only need updated surveys. The need for updating would originate from environmental changes but the surveys might be readily available with little to no modification. For instance, a similar survey to the one conducted by the BalticStern project (Ahtiainen *et al.* 2013) (Czajkowski *et al.* 2015) could be repeated relatively easily. This would provide important insights on how citizens' willingness-to-pay for the recreational benefits of a cleaner Baltic Sea changes.

Taking the time and resource constraints of obtaining more precise information into account might lead us to 1) accept the wide ranges of CBA results and simply emphasize other decision-making protocols or 2) decide how heavily to invest in the CBA. The critical issue is to avoid unintentionally under-resourced CBAs which will not be able to provide solid policy support. In other words, the availability of and the need for time and resources should be carefully considered to assess when a CBA would realistically support decision-making.



6.4. Details on the assessment results for the cost-benefit assessment

CBA has been used at least 12 times to assess whether projects within the Baltic Sea area are desirable for the society (Table 24). These analyses covered topics such as recreational benefits, improved water quality, and the value of recreational and commercial fisheries. The economic and social costs and benefits of protecting the Baltic Sea is becoming increasingly important to HELCOM's work. In the future, more regionally coordinated methods for analyses of costs and benefits to achieve good environmental status should be developed and applied.

This assessment briefly reviews these 12 identified CBAs from the Baltic Sea (Table 24) and dives more deeply into two of them to explore how different data environments affect a CBA.

Comparing Baltic Sea CBAs from different data environments can further illustrate the state-of-the-art for Baltic Sea CBAs. Bostedt et al. (2020) considers the implementation of temporary no-take zones in Sweden and Christensen et al. (2021) considers a broader set of management measures to clean-up marine litter from riverine sources Baltic Sea wide. The uncertainty regarding costs and benefits to fisheries and biodiversity from no-take zones can be relatively well quantified and constrained. While there are always uncertainties regarding population dynamics and their relation to the marine food web and fishing pressure, the basic drivers and pressures are well understood. Marine litter is more ambiguous. The damages from marine litter depend on its short- and long-term effects on human and ecosystem health. Neither of these is yet understood. The fact that microplastics are so ubiguitous in ecosystems and even in human body raises concerns of health risks, but the effects of this are not clear (Vethaak & Legler 2021). So, any benefit estimate founded on health effects will be extremely uncertain. Furthermore, it is likely that our perceptions regarding the effects of marine litter on pleasure we derive from recreational activities hinges on our perceptions on how detrimental it is for the marine environment, which is uncertain. Finally, as the research field is rather novel, technologies and their costs for avoiding or abating marine litter are not well developed.

Bostedt *et al.* (2020) estimates the costs and benefits of the notake zones as a fisheries management tool to restore fish populations. They summarize the biological effects of the no-take zones and estimate the benefits as recreational and commercial fishing values from future increases in the fish stock. The costs arise from the effort displacement effect. When the fisheries were relocated to adjacent areas, the fisheries benefits outweighed the costs and when assuming no fisheries were relocated, the costs were higher than the benefits in some scenarios. However, the estimation of fishers' behaviour and the quality of surrounding areas for fishing was based on several assumptions. This suggests that the analysis might benefit from a better understanding of the costs.

Christensen *et al.* (2021) proposes a framework to spatially prioritize the clean-up efforts given the regional sources of marine litter. The suggested optimization framework considers the impacts of litter on ecosystem functioning and the cost-efficiency of clean-up technologies. The latter is important as the available resources are often limited. The cost-benefit analysis presents the reduced litter concentration and improved ecosystem functioning as the benefit of clean-up measures. The cleaning benefit function is estimated for sensitive Natura2000 areas in the Baltic Sea. The study does not use absolute values to estimate the ecosystem benefits, rather it examines the relative differences between areas. This ap-



 Table 24. An overview of 12 peer-reviewed studies reporting cost-benefit analyses performed within the Baltic Sea.

Reference	Objective	Countries	Benefits	Costs	Conclusions
Andersson & Iveham- mar (2017)	Implementing dynamic route planning	Whole Baltic Sea	Emission reductions (NOx, PM, SO2, CARBON DIOXIDE) and cost sav- ings for ship owners	Implementing system of Vessel Traffic Service (VTS) centres	Benefits exceed the costs by €84–98 million per year
Azevedo (2020)	Moving Rubjerg Knude lighthouse 70 metres from the cliff edge	Denmark	Preservation of recreational value	Investment costs	Benefits (between €5.5m - 133m) exceed costs (€700 000)
Borger et al. (2016)	Finnish programmes of measures (PoMs)	Finland	Benefits associated with biological diversity, Food webs, eutrophica- tion	Costs of implementing PoMs	Benefits (€300–894 m) exceed costs (€140 m)
Bostedt <i>et al.</i> (2020)	Implementation of tem- porary no-take zones	Sweden	Value of the future increase of the fish stock size	Lost value of fishing	Benefits exceed costs for most scenarios
Christensen <i>et al.</i> (2021)	Marine litter clean-up	Major rivers in the Baltic Sea	Reduced decline of eco- system provisioning	Clean-up considering different technologies	Identifies the most favourable areas to clean-up
Helle <i>et al.</i> (2015)	Measures to improve oil spill response capacity: purchasing an automatic alarm system and/or new combating vessel	Finland	Avoided clean-up costs and environmental damage	Purchase and maintenance costs of automatic alarm system and/or new combating vessel	For the implementation of the automatic alarm system, the benefits exceed the costs, whereas the costs of the new vessel exceed the benefits
Hyytiainen et al. (2015)	Various policy goals to decrease nutrient pollution	All Baltic Sea countries	Improved water quality	Nutrient abatement	Benefits exceed the costs for Baltic Sea as a whole, but not for all Baltic Sea countries
Kallio-Nyberg <i>et al.</i> (2013)	Hatchery smolt releases in the Baltic Sea	Finland, Sweden	Value of catch for com- mercial fishermen	Market price of reared smolts, transport and release costs	Unclear whether benefits or costs are higher: conclusions depend on discount rate, recapture rate, etc.
Noring <i>et al.</i> (2016)	Measures to improve the environmental sta- tus in Swedish coastal waters by reducing Tributyltin (TBT)	Sweden	Decreased impacts on ecosystems	Boat washers, washing facilities with filters, tanks, and separators	Benefits exceed costs in almost all scenarios except when costs are high and willingness-to- pay estimates are low
Ollikainen <i>et al</i> . (2016)	Pumping of oxygen-rich water to anoxic bottoms of the Baltic Sea	Sweden and Finland	Citizens' willingness to pay for improved water quality due to the reduced release of phosphorus from anoxic bottoms	Costs of oxygenation pumping	Reduction of external loads produces higher annual net benefits and higher present value than oxygenating anoxic bottoms by pumping in the coastal areas of the Gulf of Finland
Van der Pol <i>et al</i> . (2021)	Coastal flood protection strategies	Germany	Avoided damages from sea level rise given the probability of annual flooding happening	Investment and annual maintenance costs	Benefits exceed costs for some areas (60.4- 65.4 km of the coastline of Schleswig-Holstein, and 78.1-189.4 km 380 of the coastline of Mecklenburg-Vorpom- mern)
Åstrom <i>et al.</i> (2018)	Implementing a Nitro- gen Emission Control Area (NECA)	Whole Baltic Sea	Value of avoided climate change-, crop growth-, and human health impacts	Annualised invest- ments, operation & maintenance, and fuel penalty costs	Benefits exceed costs for most scenarios, but less convincingly for a Baltic Sea NECA



proach is suitable for ranking between areas but more detailed information about the ecosystem impacts should be available when investment decisions are made. That is, the severity of harmful impacts of litter on marine and coastal species and habitats should be assessed. Further, the seasonal patterns of litter influx and the varying sensitivity of ecosystems between seasons might guide the decisions. In this case study, the litter influx was considered as constant, and seasonal variation was not taken into account.

Both CBAs have their merits to support decision-making. Bostedt *et al.* (2020) utilizes both biological and economic information on an exploited population in assessing the impacts of regional policy actions. Further, both the short- and long-term impacts on fishing economy are considered. The study gives valuable insights in assessing the trade-offs between costs, benefits, and the com-

pliance of local stakeholders. However, the data limitations and the use of assumptions in the study should be critically evaluated. For decision-making purposes, it should be assessed if additional information could be obtainable with reasonable cost and effort. The decision analysis aims for identifying the policies that maximize the expected benefits and minimize the costs. Sometimes, however, the scenario producing the highest benefit may be the most uncertain and there is a possibility that the objectives are not met. For this reason, the uncertainty in the CBAs should be examined, communicated, and reduced if possible.

Christensen *et al.* (2021) provides a framework for different cost-benefit problem categories to support decision making on marine litter clean-up. Their analysis is not an explicit environmental CBA although it includes almost all its components. They

Table 25. Indicative evaluation of general information conditions for cost-benefit analyses by topic. The evaluation of some topics is supported by literature (see citations); however, the remaining evaluations are based on expert opinion. Additionally, the evaluation regards general information conditions for broad topics and, as a result, there will be variability present across all evaluations. Indicative evaluation ranges from very poor (ooo) to very good (ooo).

Торіс	Enviro	nmental information	Socio- inform	economic abatement cost ation		economic abatement t information	Literature reviewing global or regional information conditions
Biodiversity/habitats	●000	Complicated by high complexity and deficient ecological data	●000	Variable, dependent on the primary pressure(s)	••00	Non-market valuations are available	
Birds	••00	Variable, dependent on the primary pressure(s)	••00	Variable, dependent on the primary pressure(s)	0000	Not typical to evaluate non-market benefits separately for this topic (included in biodiversity benefit assessments)	
Fish	•••0	Dependent on commercial value of species. Multi-spe- cies/ecosystem modelling still improving	•••0	Dependent on commercial value of species, typically high	•••0	Dependent on commercial value of species, typically high	
Hazardous substances	•000	Highly variable, but frequently once a substance generates sufficient concern to attract significant research investment, that substance is increasingly regulated	●000	Highly dependent on the substance and available substitutes	●000	Valuations of human health may be used	
Marine mammals	••00	Variable, dependent on the primary pressure(s)	•••0	Variable, dependent on the primary pressure(s)	0000	Not typical to evaluate non-market benefits separately for this topic (included in biodiversity benefit assessments)	
Marine litter	•000	Complicated by high inter- disciplinary	●000	Data deficient, most avail- able technology solutions are immature	••00	Non-market valuations are available	Christensen <i>et al.</i> (2021) Stoever <i>et al.</i> (2021)
Non-indigenous species	••00	Highly variable, but data exists for the most impactful species	●000	Large data deficiencies exist	0000	Large data deficiencies exist	ICUN (2018)
Nutrients	•••0	Long time-lags and remaining uncertainties regarding internal cycling increase uncertainty	••••	Very high data availability	•••0	Long time-lags and high levels of non-market bene- fits increase uncertainty	Halkos and Galani (2014) Ahtiainen (2016)
Underwater noise	•000	Complicated by high inter- disciplinary and deficient ecological data	•••0	Costs are generally related to technology implementa- tion or operational chang- es. Site specific variation is high reducing accuracy of a broad analysis	0000	Difficult to estimate with- out a better understanding of environmental impact	Rijkswaterstaat (2015)

map the economic landscape of clean-up alternatives rather comprehensively by looking at cost minimizing solutions to reach certain ambient pollutant levels on one side, and by looking at benefit maximizing solutions for fixed protection budget on the other. This study makes good use of the information about the costs and the spatial need for clean-up efforts. It is also quite suitable for highlighting the multidimensional and multidisciplinary information needs for such problems. From their approach, for instance, it can be easily identified that data on what kind of species and habitats would benefit the most from clean-up actions were beneficial for better decision-making. The more detailed information about ecosystem functioning (for example, species abundance or habitat quality) could have been accessible in the Baltic Sea with reasonable resources. The clearest difference to a conventional CBA is that their benefits of ecosystem services were not monetized. They show that the complexities in physical modelling are the most topical ones right now. Adding the uncertainties of benefit estimates would have blurred the picture. Their approach is essentially an amended cost-effectiveness-analysis (CEA) approaching environmental CBA. It gives useful information concerning the relative efficiency of alternatives. They compare the alternatives in terms of the ratio of their costs and a quantified, but not monetized, effectiveness measure, in the spirit of CEA described by Boardman et al. (2018). CEAs have been used in the Baltic Sea to

assess the total costs of policies (for examples, see Hyytiäinen and Ahlvik 2015, Oinonen *et al.* 2016).

Bostedt *et al.* (2020) and Christensen *et al.* (2021) provide good examples of the typical data environment for fisheries and marine litter, respectively. While each CBA has unique data requirements, a general review of the current Baltic Sea CBA data environments by topic is possible. Table 25 includes an indicative data review for nine broad environmental topics. Additionally, Table 26 provides a closer look at the topic of marine litter and reviews each of the nine identified CBA steps from the introduction for that topic. Finally, a <u>literature review of cost data relating to marine litter</u> has been compiled and can be downloaded online (<u>Data collation on costs of measures for improving state of the marine environment</u>). Development and maintenance of such databases could be a significant tool in advancing CBA for low knowledge topics.



6.5. How was the assessment of costbenefit carried out?

The studies listed in table 24 were identified during a literature review; details are available in Annex 1. Evaluations present in Tables 25 and 26 are based on the expert opinion of the assessment authors.

Table 26. Requirements, challenges and recommendations for Baltic Sea marine litter CBAs.

Step of CBA	Required information/ data	Main challenges, uncertainties	Recommendations for the future sea region work
1. Identify alternatives	Potential prevention and cleanup alternatives	 Pollution source identification Many alternatives are unidentified or immature with unclear impacts 	Information sharing Incentivize innovation, research and development
Identify affected population and area	 Physical marine model Litter transport models Non-market valuation of litter impact 	 Litter transport models quickly improving but still under development Valuation surveys can be expensive, difficult and are highly vulnerable to uncertainties from ecological and technological understandings 	 Incentivize innovation, research and development
Identify impacts (costs and benefits)	 Ecological and human health impacts and their economic damage/benefit Prevention and cleanup effects and their costs Non-market value of litter impact 	High interdisciplinarity Immature data environment across all disciplines	 Incentivize making data publicly available and be prepared to host such data when appropriate Encourage interdisciplinary research at the human health-environment nexus
4. Identify impacts over time	 Technological learning curve description Characteristics of potential prevention and cleanup alternatives Plastic burial and decay rates 	 Technological learning curve description only clear in retrospect Analyses on plastic decay rates requires long-term assessments 	
5. Monetize impacts	 Value of human health Non-market value of the environmental impacts of litter Market value of the environmental impacts of litter 	 Impacts are extremely broad for marine litter (aesthetic, ecological, human health, etc.) which complicates valuation Accumulated uncertainties over the previous steps 	
6. Calculate present value of benefits and costs	 Expected flow of monetized costs and benefits through time and their uncertainties 	 Accumulated uncertainties over the pre- vious steps and over time can be so large that the analysis is uninformative 	
7. Calculate net benefits	No additional information required		
8. Perform sensitivity analysis	No additional information required		
9. Make recommendation	No additional information required		Follow the precautionary principle until an informative CBA can be developed.



7. Results for the driver indicator assessment



Assessment results in short

For HOLAS 3 purposes, drivers were considered to be "societal and environmental factors that, via their effect on human behaviour or environmental conditions, may influence activities, pressures, or the state of the marine environment". To make the information on drivers useful in an assessment context, they should be connected with other DAPSIM framework components through explanatory proxies. Thus, driver indicators are explanatory proxies that can be quantified or succinctly described and are linked to changes in drivers.

In HOLAS 3 assessment, a limited number of drivers and driver indicators were explored, focusing on testing the driver – driver indicator methodology using selected proof-of-concept examples. Please note that driver indicators are different than the HELCOM core indicators. A brief summary of relevant drivers of relevance to each topic are provided in driver indicator fact sheets and a more detailed overview of these are available in drivers section in this document. Driver indicator fact sheets were developed for the following driver indicators to be used in HOLAS 3 assessment:

- Agricultural nutrient balance
- Wastewater treatment
- Total allowable catch
- Fishery operations

These indicators can be used as a partial quantified proxy for the drivers of demographics, consumer demand, globalization, subsidies, regulations, technology adoption, investment, political will, socio-economic settings, macroeconomic conditions, and international relations.



7.1. Introduction to the development of potential driver indicators

7.1.1 Drivers

DPSIR, BPSIR, DAPSI(W)R(M), and DAPSIM are all members of the same family of causal frameworks seeking to aid the understanding of socio-ecological systems through a simplification of key components (EC 1999) (Burkhard & Muller 2008) (Sundblad et al. 2014) (Elliot et al. 2017) (HELCOM 2020). DAPSIM (Driver-Activity-Pres-

sure-State-Impact-Measure; Figure 43) is the framework utilized in HELCOM (HELCOM, 2020). Each component in these frameworks have connections to one or more other components that allow for effects to be qualitatively or quantitatively tracked throughout the framework. In these frameworks the D stands for drivers (or B for behaviour in frameworks that target only societal drivers) and despite the prevalence of this family of frameworks, no consensus exists regarding the definition of a driver (or behaviour). Definitions from several relevant organizations are included below.

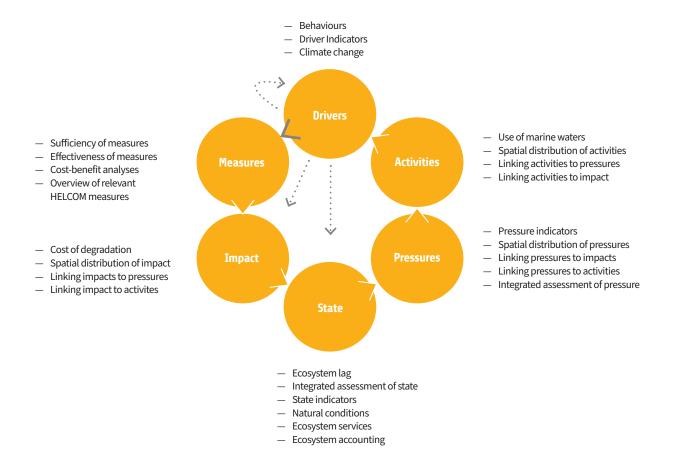


Figure 43. Initial representation of how the various topic planned for inclusion in HOLAS 3 are divided across the DAPSIM assessment framework. As it was shown with blue arrows, it is envisioned that drivers elucidate relationships with human activities, pressures, and other drivers in the DAPSIM framework.

- Drivers of change are all the factors that, directly or indirectly, cause changes in nature, anthropogenic assets, nature's contributions to people and a good quality of life – IPBES Glossary (IPBES, 2019)
- A driver is any natural or human-induced factor that directly or indirectly causes a change in an ecosystem – Millennium Ecosystem Assessment (Nelson et al., 2005)
- Drivers are factors that influence behaviours of actors and are significant in terms of pressures on the marine environment
 Swedish Institute for the Marine Environment (Sundblad et al., 2021)
- Driving force In the EEA indicator system, indicators for driving forces describe the social, demographic and economic developments in societies and the corresponding changes in lifestyles, overall levels of consumption and production patterns – European Environment Agency glossary (EEA, 2021).

Although it is regarded too early to decide a definition for HELCOM of drivers, a common understanding of the driver concept is vital for driver indicator work HOLAS 3 assessment. For the purposes of work within the HOLAS 3 assessment, drivers were considered as "societal and environmental factors that, via their effect on human behaviour or environmental conditions, may influence activities, pressures, or the state of the marine environment".

Drivers and driver indicators can be linked to the other components of the DAPSIM framework, and these relationships can identify influences behind environmental problems, which can be used for evaluation of existing measures, design of new measures and provide contextual support and additional explanatory power for other environmental assessments and evaluations such as HELCOM core indicator evaluation.

7.1.2 Driver indicators

Driver indicators have a two-fold purpose. Firstly, they provide a practical example of the impact of often abstract drivers, allowing for a more robust qualitative connection to be made between powerful but complex factors and the condition of the regional environment. Secondly, changes in these driver indicators can in some cases be linked to the broader DAPSIM framework to provide a more direct and potentially quantifiable impact on the environment. Such links can be used to inform a range of HELCOM priorities such as the evaluation of the effectiveness and sufficiency of measures.

In order to make the information on drivers useful in an assessment context, they should be connected with other DAPSIM framework components with explanatory proxies. Therefore, quantification of drivers and understanding the trends are desirable to ensure a concrete link from information on drivers to

the other DAPSIM components and thus, for achieving efficient marine governance and healthy marine ecosystems. Using driver indicators (proxies that can be quantified or succinctly described and infer changes in drivers), driver analyses that can support the understanding of trends, inform policy makers, and help to identify efficient measures. Noting that changes in drivers such as demographics and consumer demand tend to occur gradually, it can be difficult to detect them within the scope of HOLAS assessment that are conducted every six years.

Although there are several potential benefits of analysing drivers and identifying driver indicators, interacting and ubiquitous influences of most drivers makes developing indicators for single drivers generally infeasible. It can be said that identifying strong relationships between specific drivers and selected indicators is a more practical goal that could be achieved in the future. This approach could highlight drivers with a notably strong connection to the driver indicator while still acknowledging the influence of other drivers.

In this initial effort, a set of driver indicators based on proof-of-concept example pressures will be developed and refined over time to cover as many driver aspects as relevant. However, it should be noted that the requirement for data in a driver indicator does limit the drivers that can be covered. Therefore, qualitative consideration of other aspects of drivers will be also considered. It should be noted that driver indicators that do not change with changing environmental conditions are still valuable as they may be experiencing a time lag or indicate a societal aspect that does not have a strong effect on the environment. Finally, although drivers, and therefore driver indicators, may exhibit intra-regional variation, HOLAS 3 prioritized regional scale development.



7.2.1 Relevant Drivers

Demographics

Demographics (characteristics of a population) can help us understand the pressures on the marine environment. For instance, the size and growth rate of a population can affect the demand for marine resources and the amount of pollution produced. Population growth can also have social and economic effects, such as increased demand for public services and infrastructure (Sands et al. 2014). Additionally, the distribution of a population across a region can impact the distribution of pressure on the marine environment, as different areas may have different levels of population density and different patterns of resource use (de Sherbinin et al. 2007). All changes in demographics are likely to have an impact on other drivers such as consumer demand and globalization, therefore global demographics are also likely to impact regional activities (Hazell & Wood 2008).

Consumer demand

Consumer demand is an important factor that can influence the pressures on the marine environment. For example, as consumers demand more seafood, there is an increased demand for fishing, which can put pressure on marine ecosystems (Pihlainen et al. 2020). In agriculture, the demand for animal-based protein, such as

meat and dairy, can drive the production of feed crops like corn and soy. This can lead to the use of fertilizers and other chemicals that can wash into the sea and cause pollution (Sands et al. 2014).

Globalization

Globalization has the potential to affect the pressures on the marine environment in several ways (Jacques 2016). As the world becomes more interconnected and as more people and businesses have access to them, there may be a growing demand for marine resources like seafood (Sands et al. 2014). This can put pressure on marine ecosystems and lead to overfishing and other negative impacts. Globalization can also cause environmental problems, such as pollution, to move across national borders, making it more challenging to address these issues and protect the marine environment. For instance, the global trade in agricultural products can lead to the movement of invasive species across national borders by shipping activity, making it more difficult to address these issues and protect the marine environment.

Subsidies

Subsidies are a type of financial support provided by governments to certain industries or activities. In the context of the marine environment, subsidies can have both positive and negative impacts on the marine environment. On the positive side, subsidies can help to support the sustainable use of marine resources, such as by providing incentives for fishermen to use sustainable fishing practices. Subsidies can also support sustainable agricultural activities and promote the health of rural economies and ensure a domestic food supply (Hazell & Wood 2008; Huang et al. 2010; Springmann & Freund 2022). On the negative side, subsidies for fishing activity can encourage overfishing and put pressure on marine ecosystems. Similarly, subsidies can also support activities that harm the marine environment, such as the extraction of fossil fuels from the sea.

Regulations

Regulations can play an important role in mitigating the pressures on the sea. For example, regulations on fishing can help to prevent overfishing and protect marine ecosystems (Marchal et al. 2016) (Borges 2018). Agriculture regulations can also help to prevent pollution and other negative impacts on the sea (EC 2021a). For instance, regulations on the use of fertilizers and pesticides can help to reduce the amount of chemicals into the sea. Regulations on the management of animal waste can also help to prevent pollution from this source.

Macroeconomic conditions

Macroeconomic conditions refer to the overall state of an economy, including factors such as GDP, inflation, unemployment, and trade balances. In the context of the marine environment, macroeconomic conditions can impact the pressures on the sea in several ways. For example, a strong economy can lead to increased demand for marine resources, such as seafood, oil, and gas, which can put pressure on marine ecosystems (Sumaila et al., 2008). Similarly, a weak economy can lead to reduced demand for these resources, which can have a negative impact on the industries that rely on them. Further, inflation can impact the profitability of several maritime activities. For instance, the increase in fuel price was observed in the recent years, which substantially increased operational costs of vessels (Sumaila et al., 2010; Cheilari et al., 2013).



Technology adoption

The adoption of new technologies can impact the pressures on the marine environment in several ways. For example, commercial fisheries constantly adopt new technologies to remain economically competitive, increase the value of their catch, decrease costs, aid navigation, and to improve safety at sea (Tietze et al. 2005). Potentially, new fishing gear and methods can help to reduce the impact of fishing on marine ecosystems. Similarly, new fishing technologies, such as fish-finding sonar, can help to improve the efficiency of fishing operations and reduce the impact on marine ecosystems (Marchal 2006, Eigaard et al. 2014). On the other hand, new technologies can also contribute to the pressures on the marine environment. For example, new extraction technologies can make it possible to access previously untapped fish populations, leading to increased demand and potential negative impacts.

Investment

Investments can have a significant impact on the pressures on the sea. For instance, investments in marine conservation and management can help to reduce the negative impacts of human activities on the sea. Investments in wastewater treatment plants can also have a positive impact on the marine environment. To control discharge of pollutants from municipalities and industries, effective investments are vital (UNEP 2005) and by investing in these facilities, governments can help to reduce the amount of pollution that enters the sea and protect marine ecosystems. European Union supports Member States by deploying several funding instruments to support these investments. However, existing facilities and corresponding sunk costs can be a significant barrier to new investments, because it is a large and costly investment to replace functioning treatment plants with newer, more effective technologies.

Political will

Political will refers to the willingness of governments and other political leaders to take action on important issues. Without political will, it can be difficult to implement the policies and regulations needed to protect the marine environment and reduce the negative impacts of human activities on the sea. For instance, political will is essential to control fishing pressure and can be considered as the main driver to manage and protect important fish stocks with concrete actions in the Baltic Sea (Borges 2018). In terms of agriculture, governments and other political leaders must be willing to implement and enforce regulations on the use of fertilizers, pesticides, and other chemicals in agriculture. Similarly, political will is also critical for investing in wastewater treatment facilities. Without the support of political leaders, it can be difficult to secure the funding and other resources needed to build and maintain these facilities.

Socio-economic setting

The socio-economic setting, or the social and economic conditions in a particular area, can drive the management of the marine environment. For instance, implementing regulations to protect the marine environment can limit the ability of certain industries to access marine resources, such as by imposing catch limits on fisheries. This can reduce the profitability of these industries and potentially lead to job losses in affected communities. It is important to carefully consider these potential impacts and to design conservation measures in a way that minimizes negative impacts and maximizes the positive benefits to employment and the economy.

International relations

International relations or the interactions between nations and other international actors, can impact the pressures on the marine environment in a number of ways. For example, international agreements and treaties can help to regulate the use of marine resources and protect the sea from pollution and other environmental threats. These agreements can also provide a framework for international cooperation on marine conservation and management efforts. Additionally, international relations can also influence the demand for marine resources and the level of investment in the protection of the marine environment. For example, international trade agreements can impact the demand for seafood and other marine products, and international development assistance can support marine conservation and management efforts.

7.2.2 Driver indicators

Agricultural Nutrient Balance

Various drivers determine the size and structure of the agricultural sector in the region. Globalization, demographics and changing consumer demand broadly influence agriculture through market forces (Hazell and Wood 2008; Sands et al. 2014; Pihlainen et al. 2020). Agricultural subsidies and regulation can be applied to reinforce or weaken those market forces (Huang et al. 2010, Springmann and Freund, 2022). Adoption or rejection of technologies such as precision fertilization and advanced crop protection may offer opportunities to simultaneously meet a variety of economic or regulatory goals by e.g., increasing yields without creating additional environmental impacts (Sands et al. 2014, Capell et al. 2021, Pardey and Alston 2021).

Agricultural nutrient balance in the Baltic Sea region has been relatively stable over the past decade although several national trends were observed. Both in nutrient inputs and outputs, Poland has the highest relative contribution. All Baltic Sea countries have nitrogen surpluses per hectare (Figure 44), and the highest surplus values were observed in Denmark driven by high inputs from manure production. Germany and Latvia have shown a decreasing nitrogen surplus trend. Denmark, Germany, and Poland have the highest nitrogen surplus per hectare in parallel with high levels of animal husbandry and crop production. Unlike nitrogen, phosphorus balance shows a more diverse picture with both deficiencies and surpluses (Figure 45). Germany, Estonia, Lithuania and Sweden have shown phosphorus deficiency and the highest deficiency values were observed in Estonia.

In terms of explanation of the input of nutrient pressure, the driver indicators have clarity of impact, while their proximity to the related drivers is relatively poor. Identified trends in nutrient balance components may reflect the nitrogen and phosphorus input to the Baltic Sea, however, these indicators cannot be closely linked to specific relevant drivers like consumer demand, globalization or demographics in the Baltic Sea. Future work should focus on the potential data sources of optimal driver indicators such as use of best available technologies and subsidies and developing more advanced market metrics such as apparent per capita use and self-sufficiency rates.

More information is provided in the agricultural nutrient balance <u>driver indicator fact sheet</u>.

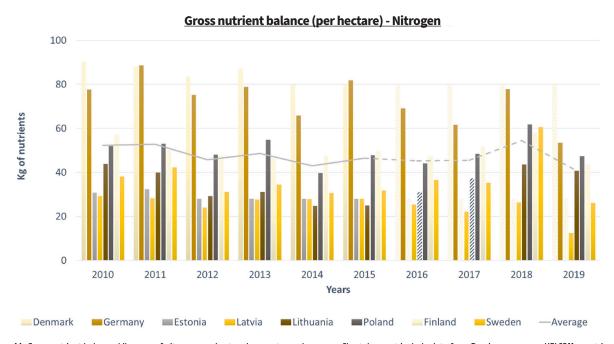


Figure 44. Gross nutrient balance, kilogram of nitrogen per hectare by country and average. Chart does not include data from Russia or any non-HELCOM countries. Data points based on the assumption of no change are indicated with hatched pattern and average line for these years are indicated with dotted pattern. The data in Eurostat has good temporal coverage for Germany, Poland, Finland, Sweden, Lithuania and Latvia thus the confidence is considered as high. Source: Eurostat 2022j

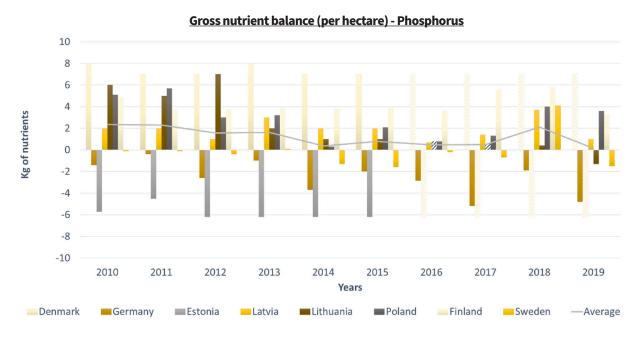


Figure 45. Gross nutrient balance, kilogram of phosphorus per hectare by country and average. Chart does not include data from Russia or any non-HELCOM countries. Data points based on the assumption of no change are indicated with hatched pattern. The data in Eurostat has good temporal coverage for Germany, Poland, Finland, Sweden, Lithuania and Latvia thus the confidence is considered as high. Source: Eurostat 2022j



Wastewater Treatment

Various drivers determine the extent and efficiency of wastewater treatment in the Baltic Sea region such as political will, investment, regulations, and technology adoption. Political will is the main driver to deliver this very basic public service vital for the protection of public health and the environment, and it defines the extent of the investment in wastewater treatment facilities. Lack of political will and insufficient investment in wastewater treatment facilities and collection systems, lead to the uncontrolled discharge of pollutants

from municipalities and industries (UNEP 2005, Capell et al. 2021, Undemand et al. 2021).

Overall, 72% of the Baltic Sea catchment area population is connected to tertiary wastewater treatment plants (Figure 46) (Eurostat 2022). Over the last decade population connected to tertiary wastewater treatment facilities has been steadily increasing (Figure 47). There is a decreasing trend in secondary wastewater treatment facilities due to implementation of tertiary treatment plants and there is a very low number of facilities providing only primary treatment

Tertiary Wastewater Treatment

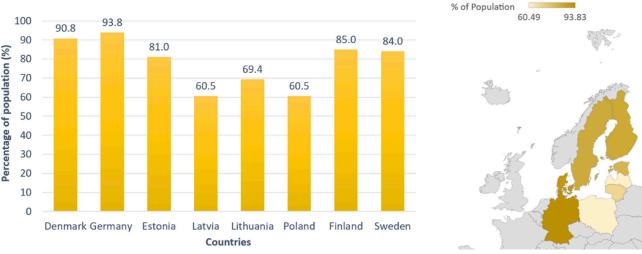


Figure 46. Percentage of total population connected to tertiary wastewater treatment plants in Baltic Sea countries in 2020. Chart does not include data from Russia or any non-HELCOM countries due to lack of data. Source: Eurostat 2022k.

Population connected to urban an other wastewater treatment plants

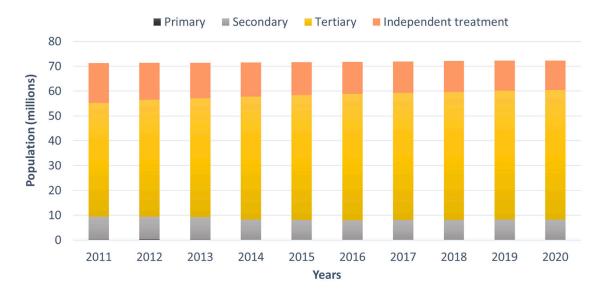


Figure 47. Population connected to urban and other wastewater treatment plants in Baltic Sea countries. Chart colours represents independent, primary, secondary, and tertiary treatment facilities. Part of the population connected to the primary treatment plants is very small and thus, not visible. Chart does not include data from Russia or any non-HELCOM countries due to lack of data. Source: Eurostat 2022k

in the Baltic Sea countries. Baltic Sea countries' population trend has been relatively stable over the past 20 years.

Implemented driver indicators have high clarity of impact in terms of explanation of the input of nutrient pressure, and their proximity to the related drivers is relatively high. Identified trends in the presence and efficiency of wastewater treatment facilities may reflect the nitrogen and phosphorus input to the Baltic Sea. Further, these indicators can be closely linked to specific relevant drivers such as political will, investment, regulations and technology adoption. Future work should focus on the data quality on population distribution and characteristics.

More information is provided in the wastewater treatment $\underline{\text{driver}}$ indicator fact sheet.

Total Allowable Catch

Various drivers determine the negotiations and agreements over Total Allowable Catch (TAC) in the Baltic Sea region. Political will is the main driver to manage and protect important fish stocks with concrete actions in the Baltic Sea (Borges 2018). In addition, the socio-economic setting of fisheries is another important driver regarding the consequences of limitations on the sector (EC, 2009). Further, international relations influence the decisions on fishing quotas since there are countries using different regulatory frameworks.

Consideration of scientific advice is vital in TAC decisions; however, the scientific advice has not been entirely followed by the policymakers over the last 20 years. Data shows that annual TACs by tonnes were 11%, 8% and 5% above scientific advice on average during the HOLAS 1, HOLAS 2 and HOLAS 3 assessment periods, respectively (Figure 48). Observed excess TACs by

Total Excess TAC by weight (%) in the Baltic Sea countries between 2001-2021

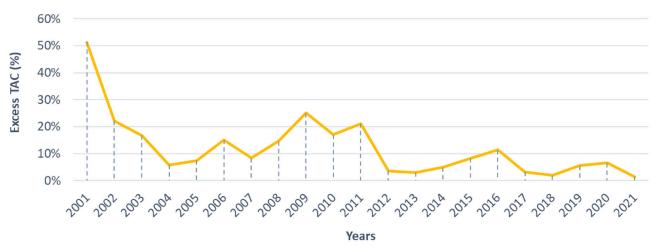


Figure 48. Total Excess TAC (Total allowable catch above ICES advice) by tonnes as percentage in the Baltic Sea countries between 2001–2020. Chart does not include data from Russia or any non-HELCOM countries. Note that the catch value below the TAC value was not considered in the calculation and the chart presents TAC values that are above ICES advice. TAC values for Atlantic Salmon in subdivisions 22–31 was not considered in this calculation due to the given unit value. Source: ICES stock assessments 2022a-k

Number of TACs above ICES advice 100% 10 9 90% 8 80% 7 70% Proportion of TACs **Number of TACs** 6 60% 5 50% 4 40% 3 30% 20% 2 1 10% n 0% 2009 2018 2006 2008 2010 2016 2017 2012 2012 2013 2014 2015

Figure 49. Number of TACs (Total allowable catch) set above ICES advice in Baltic Sea countries between 2001–2021. Chart does not include data from Russia or any non-HELCOM countries. In total, 10 stocks were analysed in this chart including Atlantic salmon (subdivisions 22–31, subdivision 32), cod (subdivisions 22–24, subdivisions 25–32), herring (subdivision 28.1, subdivisions 25–27, 28.2, 29, 32, subdivision 30–31, subdivisions 22–24), plaice (subdivisions 22–32), and sprat (subdivisions 22–32). Zero ICES advice (zero quota) stocks (cod subdivision 24–32 and herring subdivision 22–24) were highlighted in dark yellow colour. Source: ICES stock assessments 2022a–k.

■ Zero ICES advice in excess TACs ■ Quotas with assessment ■ Quotas above advice — Proportion of TACs above advice

tonnes were largely due to Western Baltic herring and Eastern Baltic cod fish stocks. The EC's 2022 TAC proposal suggested reductions and TACs for 2022 by tonnes are closer to the range of ICES advice compared to the previous years. This would align with the trend of shrinking excess TAC size.

Historical trends show that Baltic Sea countries are committed to reduce the size of the excess TACs, and data shows the impact of strong political will on diminishing excess TAC values (Figure 49). Although countries appear to recognize the economic and environmental danger of excess TACs, there seems to be certain reasons to maintain some fish quotas above scientific advice. This likely highlights the short-term conflicts between the environmental and socio-economic concerns.

More information is provided in the total allowable catch <u>driver</u> indicator fact sheet.

Fishery Operations

Various drivers determine the extent and efficiency of fishery operations in the Baltic Sea region. Among others, strict regulations such as catch quotas and fleet reduction initiatives, technology adoption and macroeconomic conditions have influenced the fishery operations and fleet characteristics in Baltic Sea.

Due to regulations mandating fleet capacity reductions and catch limits, the characteristics of the fishing industry in the Baltic Sea countries have changed during the last decade. Measures on fishing capacity adjustments and catch limits for particular stocks can be associated with the results of this driver indicator. Baltic Sea countries started to operate with less and older fishing vessels, and this is mainly due to structural changes in the small-scale fishery. Further, fishing effort and fishing enterprises have decreased. However, these changes did not result in lower catch quantities due to improved technology adoption such as new technology engines, electronic fish locating technology and more efficient trawl nets. Although full-time equivalent employment decreased in the region, reduced employment resulted in higher labour productivity (Figures 50 and 51).

Briefly, the fishing fleet of Baltic Sea countries is in transformation due to regulations, and economic income trends suggest the long-term viability of fishery activity is improving. Data shows that technological adoptions can compensate for reduced human power, however, the social consequences of these changes should not be disregarded.

More information is provided in the fishery operations <u>driver</u> indicator fact sheet.



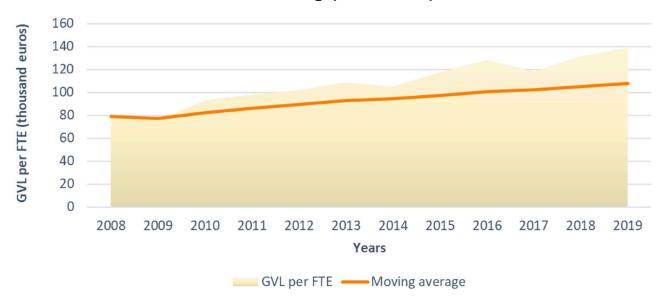


Figure 50. Gross value of landings (GVA) per full-time equivalent employee (FTE) in fishing fleets in Baltic Sea countries between 2008-2019. Orange line shows the moving average value since 2008. Chart does not include data from Russia or any non-HELCOM countries. Source: STECF 2021b.

Weight of landing and FTE employees

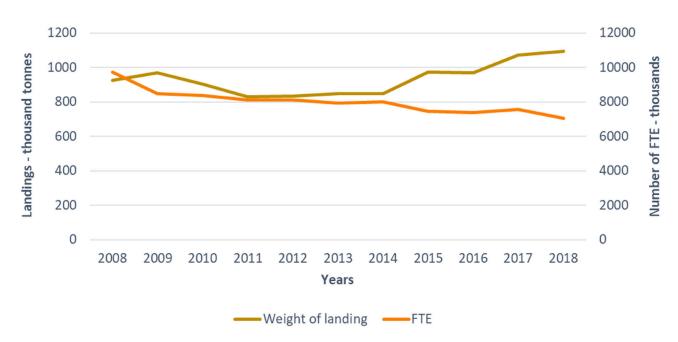


Figure 51. Weight of landings (tonnes) and full-time equivalent employees in fishing fleets in Baltic Sea countries between 2008-2018. Chart does not include data from Russia or any non-HELCOM countries. Source: STECF 2021b.



7.3. Relationship between drivers, human activities and pressures

Underlying causes of changes in human activities, such as population growth or macroeconomic conditions, can be closely interlinked with the development of pressures on the marine environment. Further, such relationships between drivers and pressures are often complex. Assessing and improving our understanding of the relationships between drivers, human activities and the development of pressures is important for identifying underlying causes of environmental changes and developing effective strategies to protect the marine environment. The results of the assessment of drivers and driver indicators should be evaluated together with pressure-related thematic assessments.



7.4. How was the assessment of driver indicators carried out?

Pressures of interest were identified by HELCOM and used as the basis for organizing expert workshops to discuss relevant drivers and driver indicators. As a result of this process and based on expert opinions, a preliminary overview of drivers relevant to the Baltic Sea region was prepared. Potential driver indicators for further development and their connections with DAP-SIM components were analysed based on existing data sources. Each driver indicator fact sheet includes data processing section explaining identified and used data sources. During the development process, contracting parties and topic experts provided regular guidance. The full methodology is available in Annex 1.

In HOLAS 3 assessment, a limited number of drivers and driver indicators were explored, focusing on testing the driver – driver indicator methodology using selected proof-of-concept examples. Please note that driver indicators are different than the HELCOM core indicators which are with quantitative threshold values to evaluate progress towards the goal of achieving

good environmental status in the Baltic Sea. A brief summary of relevant drivers of relevance to each topic are provided in driver indicator fact sheets and a more detailed overview of these are available in drivers section in this document.



7.5. Follow up and needs for the future

In HOLAS 3 assessment, a limited number of drivers and driver indicators were explored, focusing on testing the driver – driver indicator methodology using selected proof-of-concept examples. The outcomes of this initial exercise demonstrated that driver indicator trends can be compared and analysed with the HELCOM core indicator findings. For instance, positive trends in the adoption of tertiary wastewater treatment technologies can be analysed with the results of eutrophication indicators such as dissolved inorganic nitrogen (DIN). Furthermore, these comparisons can be used to evaluate the effectiveness of existing measures to protect the marine environment. These results can also reveal the need for new measures based on trends found in the driver indicators. However, this work needs more input from subject experts, a comprehensive literature review, and a better understanding of the overall picture.

A stronger understanding of the data environment for driver indicators as a whole is a clear need identified during this initial effort. Expert support on data is essential in order to enlarge the scope of driver indicator work and it is recommended to include socio-economic data experts in the future. In addition, application of global examples (Eurostat socio-economic indicators) can dramatically expand the number of indicators. Eurostat was the main socio-economic data source used in this exercise and a detailed review of available datasets in the platform is highly recommended for the future work. This review can identify both temporal and geographical scope of datasets in Eurostat.



8. Conclusions of the thematic assessment on economic and social analyses

Economic and social analyses play a crucial role in understanding the relationship between the well-being of society and the state of the environment, particularly in the context of marine management. However, the value and potential impact of these analyses depend on the availability of data. Therefore, it is important to prioritize regional coordination of data generation and sharing in order to meet the data needs and continue improving the capacity for economic and social analyses in the Baltic Sea region. These data needs may include traditional economic data, such as business statistics, as well as a range of other types of data such as marine habitat maps, assessment of marine habitat condition, cost and effectiveness of abatement measures, and more. It is important to recognize that economic and social factors already have an impact on the management of the Baltic Sea, and their importance is likely to continue growing in the future.

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Annex 1. Manuals for the assessments

- Cost of degradation assessment
- Ecosystem services assessment
- Cost-benefit analysis assessment
- Drivers and driver indicators assessment



A1.1 Cost of degradation assessment

The cost of degradation assessment is based on studies published during the HOLAS 3 period that provide estimates for at least three countries representing a variety of socio-economic and cultural contexts across the countries in the Baltic Sea region.

Description of the used GES benefit valuation studies

The studies valuing benefits of achieving GES are based on several national surveys, where data have been collected from nationally representative samples in 2017 for the Finnish study, in 2020 for the Swedish and German studies and in 2021 for the Latvian study. All studies applied the contingent valuation method, which asks citizens for their willingness to pay to achieve GES comparing to a specified reference state (Box A1). The studies used similar surveys, and included all environmental problems, which prevent achievement of GES according to assessments for the national marine waters. Description of the reference state was also specified according to the national environmental conditions. In the Finnish, German and Swed-

ish studies the current state of the national marine waters was used as the reference state, while a business-as-usual-scenario was used as the reference state in the Latvian study, accounting for the effect of measures from other policies planned by 2040. There are some differences across the studies in the reference state description, however there is no approach to take into account these differences for the cost of degradation assessment. It looks overall that due to the use of business-as-usual scenario in the Latvian study, this study provides better reference state for some valued environmental problems, thus, smaller gap to GES than if the current state was used. For instance, the amount of beach litter is specified as 30-40% of the current amount, accounting effect of a wide range of other EU policies addressing this problem. Some differences can be seen also among other studies, for instance, "new non-indigenous species arrive with increasing rate" in the Finnish study and "continuous introduction" in the German study.

The valued environmental goods have not been evaluated against the sea region assessments of the current state and definition of GES. This needs to be taken into account when interpreting the assessment result in the sea region context.





Descriptions of the reference state and GES for valuation in the used valuation studies.

Finnish and Swedish studies

Differences in the descriptions used between the studies are labeled FI and SE, respectively.

	CURRENT STATUS	GOOD STATUS
Eutrophication	Turbid water Abundant algal blooms (FI) [and overgrowth of aquatic vegetation (SE)]	Clear water Low level of algal blooms
Biodiversity	Degraded richness of habitats and species	Rich variety of habitats and species
Non-indigenous species	New non-indigenous species arrive with increasing rate	No arrival of new non-indigenous species
Fish stocks	E.g. the stocks of salmon, cod and pike perch are deteriorated Cyprinids-dominated fish community (FI) Decreased amount of predatory fish (SE)	Fish stocks, including salmon, cod and pike perch, are abundant Balanced fish community
Hazardous substances	Disturbs ecosystem and the contents exceed the safe limits for many fish species	Do not disturb ecosystem and the contents do not exceed the safe limits for any fish species
Physical impacts	Dredging, litter and underwater noise and energy locally cause disturbances for ecosystem	Dredging, litter and underwater noise and energy do not cause disturbances for ecosystem

German study

	Current status	Aim: Good environmental status
Excess nutrient enrichment	Strong algal growth Baltic Sea: Turbid water North Sea: Algae foam on the beach	Low algal growth Baltic Sea: Clear water North Sea: No algae foam on the beach
Biolocical diversity	Decreasing diversity of typical habitats and species	Stable large diversity of typical habitats and species
Non-indigenous species	Continuous introduction	No further introduction
Fish stocks	Some fish stocks in poor condition Unbalanced size and age distribution	All fish stocks are in good condition Balanced size and age distribution
Hazardous substances	Exceeding threshold values for some substances	All threshold values are met
Physical impacts and litter	Severe impairment of habitats, animals and plants through noise, damage to the seabed, cooling water and waste	No impairment of habitats, animals and plants through noise, damage to the seabed, cooling water and waste

Latvian study

"Please read carefully the description below, which describes the state of the marine environment in two situations. The state of the marine environment in 2040 without additional measures will provide some improvement, but it will not correspond to the good environmental state. If additional measures were implemented in addition to the existing and planned measures, good environmental state would be ensured in the Latvian sea waters in 2040."

Marine environmental problems	State in 2040 without additional measures	Good environmental state in 2040
Excessive accumulation of nutrients	Insufficient oxygen amount and water transparency. Intensified algae growth. Rotting algae on shore.	Good oxygen conditions and water transparency. Slow algae growth. Almost no rotting algae on shore.
Hazardous polluting substances	Increased levels of some substances, causing harm to fish and other marine organisms.	Quantities of all substances at safe levels without harm to marine life.
Alien species	New species arrive regularly (on average 1 species in 2 years).	No new species. Impact of existing species is minimized.
Marine litter	30-40% of the current amount on shore. Waste at sea harms animals and plants.	Almost no waste on shore (10% of the current amount). No harm to marine animals and plants.
Diversity of natural species	Reduced distribution and quality of underwater plants. Declining number of animals and birds for several species.	All plant, animal and bird populations typical of marine waters are in good condition.
State of fish populations	Reduced number of salmon and sea trout. Disturbed composition of fish species (little predator fish, more fish of other species).	All fish populations are in good condition. Diverse and balanced composition of fish species.



Description of the used recreational benefit valuation study

The used studies on recreational benefits have been implemented in 2016-2017 by applying an identical survey in all the three countries (Finland, Germany and Latvia). The data were collected from nationally representative samples in each country; thus, the results can be generalized to the national populations. The reference for the valuation is the current environmental conditions with respect to the used indicators according to perceptions of respondents (Box A2). Changes in recreational trips have been measured for various improvement levels. The scenario used for this assessment takes estimates for the best possible conditions ("clear" for water clarity, "never" for algal blooms and algae onshore, "high" for bird and plant diversity).



Descriptions of the environmental quality attributes and scenarios in the used valuation study.

Description of the environmental attributes and their levels for the survey (Bertram et al., 2020).

Attribute	Description	Levels
Water clarity	Water clarity indicates how deep you can see under the surface.	Turbid (0), somewhat turbid (1), somewhat clear (2), clear (3)
Appearance of blue-green algal blooms	Blue-green algae are a special type of algae that can grow intensively in the water column during the summer and can form a visible thick mat/layer on the surface of the water at some parts of the sea	Often (3), sometimes (2), seldom (1), never (0)
Amount of algae on shore	Some algae such as different typed of seaweed can be washed ashore to varying amounts and can also produce unpleasant odours during their decay	Often (3), sometimes (2), seldom (1), never (0)
Number of bird and plan species	A healthy ecosystem supports a large diversity of native species, including healthy populations of sea birds, plants and fish	Low (0), rather low (1), rather high (2), high (3)

Attribute levels in the current conditions, according to perceptions of respondents, and the valued best-case scenario (Bertram et al., 2020). For blue green algal blooms and algae onshore, higher values indicate worse conditions.

	Average perception of the cu	Average perception of the current quality (median/mean)		
Attributes			Latvia	
Water clarity	2 (somewhat clear) /2.07	1 (somewhat turbid) /1.30	2 (somewhat clear) /1.70	3 (clear)
Blue green algal blooms	1 (seldom) /0.98	1 (seldom) /1.44	1 (seldom) /1.31	0 (never)
Algae onshore	1 (seldom) /1.25	2 (sometimes) /1.55	2 (sometimes) /1.63	0 (never)
Bird and plant diversity	2 (rather high) /1.90	2 (rather high) /1.53	2 (rather high) /1.47	3 (high)



Comparison of available data on marine recreation participation rates

Table A1. Share of visitors of the sea for recreation (% of the total population) in the Baltic Sea countries. (Source: Data from various surveys.)
[1] Khedr et al. (2023), data from 2019; [2] MAREA Deliverable D.T.2.2.2 (upcoming) (http://marea.balticseaportal.net/outputs/), data from 2022; [3] Bertram et al. (2020), data from 2016; [4] Oehlmann et al. (2021), data from 2020; [5] AKTiiVS (2022), data from 2017, 2019, 2021; [6] Nordzell et al. (2020), data from 2020.

Country	Share of visitors of the sea for leisure as % of the (adult) population (data from representative samples); data collection year in parenthesis
Denmark	74% (2019)[1]
Estonia	75% (2019)[1]; 83% (2022)[2]
Finland	76% (2016) ^[3]
Germany	$49\% (2016)^{[3]}; 56\% (2019)^{[1]}; 53\% (2020)^{[4]}$
Latvia	79% (2017); 84% (2019); 83% (2021) ^[5]
Sweden	62% (2019) ^[1] ; 88% (2020) ^[6]

Value transfer approach

The benefit transfer follows the same procedure employed in HO-LAS 2, where the most appropriate study site (study country hereafter) values are transferred to the policy site (country) using value transfer methodology. First, the study site values (benefit estimates in Euros per person per year) are corrected for inflation between the year of the original study and year 2020 using the rate of change in policy country's consumer price index. Second, the transferred values were made comparable across countries using purchasing power parities for EU-27 countries at year 2020 price levels¹. Third, the transferred values were corrected to take account the relative difference in income levels represented by the gross domestic prod

uct in the study and policy countries. The most appropriate study country for a policy country was chosen in the analysis so that the nine Baltic Sea countries were divided to two income groups: countries above median gross domestic product (Denmark, Finland, Germany and Sweden) and below (Estonia, Latvia, Lithuania, Poland and Russia). Furthermore, if two or more studies were available for transfer, values were transferred from the study country with the smallest transfer error in the Czajkowski et al. (2017) background data. In Czajkowski et al. (2017) the median transfer error in country-to-country transfers was an over- or underestimation of true value by approximately 50 per cent.

$$\begin{split} \textit{CoD}_{\textit{policy country}} &= \textit{CoD}_{\textit{study country}} * \textit{CPI factor} * \textit{PPPfactor} * \textit{GDP factor} \\ \textit{Consumer pride index adjustment (CPI) factor} &= \frac{\textit{CPI}_{2020}}{\textit{CPI}_{\textit{study year}}} \\ \textit{Perchasing power parity adjustment (PPP) factor} &= \frac{1}{\textit{PPP}_{\textit{study country}}} \\ \textit{Gross domestic product adjustment (GDP) factor} &= \frac{\textit{GDP per capita}_{\textit{policy country}}}{\textit{GDP per capita}_{\textit{study country}}} \end{split}$$

Data sources: World Bank 2022b-c, OECD 2022, Eurostat 2022l.

¹ Ahtiainen et al. (2022) present values in year 2017 PPP-corrected Euros. These values were not reconverted to year 2020 PPP-correction to avoid conversion errors.



A1.2 Ecosystem service assessment

A1.2.1 Quantified benefit estimates

Quantitative Ecosystem Service (ES) benefit estimates were developed for selected regulation ESs provided by eelgrass, Fucus spp. and soft-bottom sediments. The methodology for estimating these benefits is described in the sections below. The process involves the development of separate ecosystem component distribution maps and ecosystem service provision rate maps, which are then multiplied to calculate the estimated delivery of bio-physical benefits. Variability in ecosystem service provisioning rates is discussed in a supplementary table Ecosystem service quantitative benefit estimate rates from literature.

Distribution maps for ecosystem components

Eelgrass distribution map:

The standard eelgrass distribution map used by HELCOM Map and Data Service consists of modeled or surveyed presence data submitted by the Contracting Parties (CPs) between 2011 and 2022. Direct quantification of the distribution maps would indicate 16000 km² of eelgrass in the Baltic Sea - an order of magnitude greater than available estimates (Boström et al. 2014). To improve the accuracy of our distribution maps, we used detailed bathymetry information from the EMODnet Data Portal (www.emodnet-bathymetry.eu) to filter out areas deeper than 5 meters. This depth threshold was chosen based on previous studies that have shown that eelgrass typically does not occur at depths greater than 5 meters in the Baltic Sea (Krause-Jensen et al. 2000, Nielsen et al. 2002).

The bathymetry data used in this study was collected by the European Marine Observation and Data Network (EMODnet) and has a spatial resolution of 94.32 m^2 . The data covers the entire Baltic Sea and includes depths measured in 2020. We used an ArcGIS software to mask out areas of the eelgrass distribution map that were deeper than 5 meters, resulting in a final estimated area of 5344 km^2 for the Baltic Sea.

Fucus spp. distribution map:

The Fucus spp. distribution map used in this study consists of data from the HOLAS 3 observation and modelling dataset (point data), the HOLAS 2 dataset, and the biodiversity dataset. To improve the accuracy of the distribution estimate, we used detailed bathymetry information from the EMODnet Data Portal (www.emodnet-bathymetry.eu) to filter out areas that are too deep for Fucus to occur. We used depth ratios (percentage of 1km² grid below area specific Fucus spp. depth limit) from the Torn (2006) study to determine the depth limits for different sub-basins of the Baltic Sea. Specifically, we used a 2-meter depth limit for the Kattegat, Great belts, and Sound sub-basins, a 3-meter depth limit for the Kiel bay and Bay of Mecklenburg sub-basins, and a 5-meter depth limit for the rest of the Baltic Sea.

In order to improve the quality of the modelled data, we applied a correction factor of 0.45 to the Fucus distribution areas in Estonia, based on the Fucus distribution ratio from Möller and Martin (2007). The ecosystem service provision rates used in this study are based on Fucus dry-weight, which was calculated using biomass information from Vogt and Schramm (1991). We used the Kiel Bay case study area to estimate the total weight of Fucus spp.. in 1 km² grid cell (77.6 tonnes per km²), which was then multiplied by the dry-weight ratio (0.17) from Back *et al.* (1992).

Soft-bottom sediment distribution map:

Broad-scale sediment maps are available in HELCOM Map and Data Services database for the Baltic Sea, and this data have been produced in the EUSeaMap project. Soft bottom (mud-mixed) sediment maps were used in the ecosystem service benefit estimations. These areas include classes "fine mud", "sandy mud" and "mud to sandy mud" of the original data.

In this study, we used the broad-scale sediment maps available in the HELCOM Map and Data Services database for the Baltic Sea, which were produced as part of the EUSeaMap project. These maps provide detailed information about the type and distribution of sediment in the Baltic Sea. We used the areas of soft bottom (mudmixed) sediment, which includes the "fine mud," "sandy mud," and "mud to sandy mud" classes of the original data.

We applied a GIS software to identify the locations and sizes of the sediment areas and used data from relevant studies to estimate the ecosystem services provided by these areas. This approach allowed us to generate a detailed map of the ecosystem service benefits provided by the Baltic Sea's soft bottom sediment areas.

Ecosystem service benefit estimates

Ecosystem services provided by eelgrass: Carbon, nitrogen and phosphorus assimilation

To estimate the annual assimilation rates of carbon (C), nitrogen (N), and phosphorus (P) by eelgrass in the Baltic Sea, we used a combination of data from Röhr et al. (2016) and Duarte (1990). The annual production rates (g DW m-2 y-1) from Röhr et al. were multiplied by the tissue carbon, nitrogen, and phosphorus proportions from Duarte to calculate estimates of annual carbon, nitrogen and phosphorus assimilation.

We used the IDW ArcGIS tool to interpolate these assimilation rate estimates in Finland and Denmark and produce a map of the spatial distribution of carbon, nitrogen, and phosphorus assimilation by Eelgrass in the Baltic Sea. To account for uncertainty in the estimates, we applied the standard error from Röhr *et al.* (2016) and the variability ranges from Duarte's study to generate minimum and maximum values for the assimilation rates.

Table A2. Eelgrass sampling location points used in the interpolation process for carbon, nitrogen and phosphorus assimilation ecosystem service.

Location	Latitude	Longitude
Finland	60.47	21.62
Finland	59.59	18.94
Finland	59.81	22.89
Denmark	57.09	10.01
Denmark	56.63	8.20
Denmark	55.30	10.83

Carbon, nitrogen, and phosphorus storage:

To estimate the carbon, nitrogen, and phosphorus storage rates of eelgrass in the Baltic Sea, we used data from several studies that have analysed the eelgrass profiles and carbon densities in the upper 25 cm of the sediment in different regions (Röhr *et al.* 2016, Jankowska *et al.* 2016, Dahl *et al.* 2016). Although there

are minor methodological differences between these studies, we transformed each rate to the same unit (g C m-2) to allow for comparison and analysis in the HOLAS 3 database.

The Polish estimates were based on different sampling methods (upper 10 cm of the sediment) compared to the Danish, Finnish, and Swedish estimates (upper 25 cm of the sediment). To account for this difference, we used the depth-related formulation from Duarte (1991) to calculate an approximate rate for Polish carbon storage. Using the carbon storage rates and the carbon (37%), nitrogen (2%), and phosphorus (0.2%) proportions in eelgrass from Duarte (1990), we calculated the nitrogen and phosphorus storage rates for the same sampling locations.

We created a spatial point data set showing the sampling locations and the carbon, nitrogen, and phosphorus storage rates. Using the IDW Geostatistical Analyst tool in ArcGIS, we interpolated these rates to produce a map of the spatial distribution of storage rates in the Baltic Sea. We then multiplied the storage rates by the presence of eelgrass to identify the total storage amount in each 1 km² grid cell. The point sampling locations are provided in Table A3. To express uncertainty in the estimates, we applied the rate variability to generate minimum and maximum values for the carbon storage rates (see Ecosystem service quantitative benefit estimate rates from literature).

Table A3. Eelgrass sampling location points used in the interpolation process for carbon, nitrogen, and phosphorus storage and carbon sequestration ecosystem services.

Location	Latitude	Longitude
Finland	60.47	21.62
Finland	59.59	18.94
Finland	59.81	22.89
Denmark	57.09	10.01
Denmark	56.63	8.20
Denmark	55.30	10.83
Poland	54.73	18.47

Carbon Sequestration

To estimate the annual carbon sequestration rate of eelgrass in the Baltic Sea, we used data from two studies that have investigated carbon sequestration in eelgrass sediments (Röhr *et al.* 2016 and Jankowska *et al.* 2016). Both studies estimated the annual carbon sequestration rate (t ha y-1) by multiplying the mean organic carbon density (g C cm-3) by the annual organic carbon accumulation rate (2.02 mm y-1, Duarte *et al.*, 2013). We used the same method to calculate the Sweden carbon sequestration rate using the mean carbon density values from Dahl et al. (2016).

To generate a regional sequestration rate, we calculated the weighted average of the Sweden and Finland carbon sequestra-

tion rates based on the number of core samples. We then used the IDW ArcGIS tool to interpolate these rates and produce a map of the spatial distribution of carbon sequestration by eelgrass in the Baltic Sea. We multiplied the annual carbon sequestration rates by the presence of eelgrass to identify the annual carbon sequestration amount in each 1 km² grid cell. The point sampling locations are provided in Table A3. To express uncertainty in the estimates, we applied the rate variability to generate minimum and maximum values for the carbon sequestration rates.

Ecosystem services provided by Fucus spp.

Carbon, nitrogen, and phosphorus assimilation:

To estimate the carbon, nitrogen, and phosphorus assimilation by Fucus in the Baltic Sea, we extracted annual growth rates from figures showing quasi-monthly sampling data for two locations: the Northern Baltic Proper (Lehvo *et al.*, 2001), and the Kiel Fjord (Graiff *et al.*, 2015). We approximated the monthly values and multiplied them by the corresponding number of days in each month to generate annual estimates of the growth rates.

We then multiplied the annual growth rates by the Fucus dryweight (tonnes) and the presence of Fucus in each 1 km² grid to calculate the carbon, nitrogen, and phosphorus assimilation in each grid cell. This approach allowed us to generate a map of the spatial distribution of assimilation rates in the Baltic Sea and identify the areas where Fucus is contributing the most to the assimilation of these elements.

Table A4. Carbon, nitrogen and phosphorus assimilation by Fucus spp. sampling location points used in the interpolation process.

Location	Latitude	Longtitude
Skallotholmen	59.87	23.29
Kiel fjord	54.48	10.16

Carbon, nitrogen, and phosphorus storage:

To estimate the carbon, nitrogen, and phosphorus storage by Fucus in the Baltic Sea, we used data from Balina $et\ al.\ (2015)$ study, which provides information on the chemical composition of Fucus (carbon, nitrogen, and phosphorus proportions) in the Baltic Sea. We multiplied these ratios by the Fucus dry-weight (tonnes) and the presence of Fucus in each 1 km² grid to calculate the storage amounts in each grid cell.

Ecosystem services provided in soft-bottom sediments:

Carbon sequestration

To estimate the carbon sequestration rate in the Baltic Sea, we used data from Winogradow and Pempkowiak (2013), which provides average sub-basin rates of carbon sequestration. We used these rates to interpolate a map of the spatial distribution of carbon sequestration in the Baltic Sea.

To calculate the carbon sequestration rates at each sampling location, we used the "accumulation rate minus flux rate" formula. We then multiplied these rates by the presence of soft-bottom sediment in each 1 km² grid to identify the total carbon sequestration in each grid cell. The point sampling locations are provided in Table A5. To express uncertainty in the estimates, we applied the rate variability to generate minimum and maximum values for the carbon sequestration rates.

Table A5. Carbon sequestration in soft-bottom sediments sampling location points used in the interpolation process.

Location	Latitude	Longtitude
Gulf of Bothnia	65.14	22.73
Gulf of Bothnia	64.45	22.22
Gulf of Bothnia	63.33	20.12
Gulf of Bothnia	62.98	18.91
Gulf of Finland	59.81	24.49
Gotland Deep	57.31	19.72
Gotland Deep	56.87	19.59
Gotland Deep	56.02	18.27
Gotland Deep	56.42	19.36
Danish straits	55.11	11.23
Bornholm Deep	54.94	15.69
Gotland Deep	55.66	19.17
Gdansk deep	54.60	19.05

Nitrogen burial

To estimate the nitrogen burial rate in the Baltic Sea, we used data compiled by Lønborg and Markager (2021) for a total of 12 sampling locations. We used these data to interpolate a map of the spatial distribution of nitrogen burial in the Baltic Sea.

Table A6. Nitrogen burial in soft-bottom sediments sampling location points used in the interpolation process.

Location	Latitude	Longtitude
Location	Latitude	Longulude
Bothinian Sea	65.14	22.73
Bothinian Sea	64.45	22.22
Gulf of Bothnia	62.98	18.91
Eastern Gulf of Finland	60.08	28.10
Gotland Deep	59.81	24.49
Gotland Deep	57.07	20.09
Gulf of Riga	57.54	23.63
South-west Kattegat	57.03	11.69
Kattegat/Skagerak	55.59	10.59
Bornholm Deep	55.29	16.31
Gdansk Deep	54.89	19.16
Gulf of Gdansk	54.41	19.18

To calculate the nitrogen burial rates at each sampling location, we multiplied the rates by the presence of soft-bottom sediment in each 1 $\rm km^2$ grid to identify the total nitrogen burial in each grid cell. The point sampling locations are provided in Table A6. To express uncertainty in the estimates, we applied the rate variability to generate minimum and maximum values for the nitrogen burial rates.

Denitrification

To estimate the denitrification rate in the Baltic Sea, we used data compiled by Lønborg and Markager (2021) for coastal sediment denitrification rates. We used these data to produce a map of the spatial distribution of denitrification in the coastal areas of the Baltic Sea.

To estimate denitrification rates in the open sea, we used data from the Deutsch *et al.* (2010), Bonaglia *et al.* (2014), and Jäntti (2012) studies. We interpolated these data to produce a map of denitrification rates in the open sea. We then merged the maps of coastal and open-sea denitrification rates to generate a map of the spatial distribution of denitrification in the entire Baltic Sea. The point locations for open-sea rates are provided in Table A7. To express uncertainty in the estimates, we applied the rate variability to generate minimum and maximum values for the denitrification rates.

Table A7. Denitrification in soft-bottom sediments sampling location points used in the interpolation process. HELCOM sub-basins shapefile was used to appoint coastal denitrification rates to each coastal sub-basin in the Baltic Sea.

Location (open sea points)	Latitude	Longtitude
Bothnian Bay	65.17	23.28
Bothnian Bay	63.51	21.01
Bothnian Sea	62.01	18.95
Baltic Proper (NS6-7)	56.15	19.81
Danish Straits14 (Kreidesegler)	54.27	11.74
Multiple rate for Arkona Basin*	54.74	15.43

Phosphorus burial

To estimate the phosphorus burial rates in the Baltic Sea, we used data compiled by Asmala $et\ al.\ (2017)$ for phosphorus burial rates (i.e., 1km^2 resolution shapefile). Using the IDW Geostatistical Analyst tool in ArcGIS, we interpolated these rates to produce a map of the spatial distribution of phosphorus burial rates in the Baltic Sea. We then multiplied these rates by the presence of soft-bottom sediment in each $1\ \text{km}^2$ grid to identify the total phosphorus sequestration in each grid cell.

Variance calculations

Pooled variances were calculated using

(1)
$$s_{pooled}^2 = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}$$

For studies that did not report sufficient information to directly calculate variance, variances were estimated using the approaches of Hozo *et al.* 2005, primarily the range/4 approach.



A1.2.2 Monetary ecosystem service estimation

Monetary estimates on the ES socio-economic values have been developed for relevant provisioning, regulating and cultural ES. The detailed methodology is presented for each ES.

P1 Wild fish for human and domesticated animal nutrition

The monetary value of nutrition benefits is estimated based on the market prices of fish products for relevant fish species. The approach is based on the assumption that the market price reflects the value attached by consumers to the goods in question. Such an estimate is a proxy for the value of the ES benefits. It should be taken into account also that such an estimate accounts also the contribution of human capital, might cover also the "cultural" value of fish (not only the nutrition value).

Data on the prices are taken from European Market Observatory for Fisheries and Aquaculture Products (EUMOFAP) (available at https://www.eumofa.eu/ad-hoc-queries). Data for the Baltic Sea are extracted from this source. The price data for the most common fish products in the sea region countries are used. An interval price is created for each species, where the intervals are determined primarily by the prices of various products (Table VIII). In some cases, the price intervals are impacted also by the price differences in the countries (for instance, for cod). The created unit value estimates are provided in Table A8. These prices are multiplied by the catch of relevant fish species (tons/year) in the Baltic Sea (based on ICES data) to calculate the monetary benefits of this ES.

Wild fish is used also for domesticated animal nutrition. For instance, in Germany even up to 90% of the catch of herring and sprat is used for such a purpose. The benefits for animal nutrition would be better reflected by the landing price rather than the retail price of fish products, and the landing prices are considerably lower. There is no data for the whole sea region on the proportion of the total catch used for the animal nutrition. The benefit estimate is calculated assuming that 50% of the catch of sprat and herring is used for animal nutrition, applying the landing price for this proportion.

Confidence in the estimated benefits for the Baltic Sea region is moderate, since it is calculated based on a range of prices for various fish products, but misses actual data on shares of the various products in the consumption.

Table A8. Unit values (prices) used for the monetary benefit estimation of the ES P1 "Wild fish for human and domesticated animal nutrition". (Source: Based on FUMOEAP data)

Fish species and their products	Retail/consumption price EUR/kg (based on data for 2020)	Landing price EUR/kg (based on data for 2020)
Baltic herring and its products (fillets, in oil, in sauce, canned, rollmops)	3-7.5	0.20
Sprat/sardine (fresh, canned, in oil)	2-7.5	0.17
Cod (fresh, frozen) and its products (whole, gutted, fillets)	6-9	3.0
Flounder (fresh, whole or gutted)	3 (an average price in the Baltic Sea for 2019-2021)	1.4



P3 Fish cultivated by in-situ aquaculture

The monetary value of nutrition is estimated based on the market prices of the marine aquaculture production. The approach is based on the assumption that the market price reflects the value attached by consumers to the good in question. Such estimate is a proxy for the value of the ES benefits. It should be taken into account also that such estimate accounts also the contribution of human capital. However, it is applicable for the sea region taking into account the available data.

Data on the market prices are taken from the European Market Observatory for Fisheries and Aquaculture Products (EUMOFAP) (available at https://www.eumofa.eu/aqualculture-yearly-comparison-between-ms). Data for the Baltic Sea are extracted from this source. The price data for the most common aquaculture products in the sea region countries are used. An interval price is created for each species/product, where the intervals are determined by sales and retail prices and also the price differences in the countries. The created unit value estimates are provided in Table A9. These prices are multiplied by the production (tons/year) to calculate the monetary benefits of this ES. Confidence in this estimate is moderate, since it is calculated based on a range of prices for various products, but misses actual data on shares of the various products in the consumption.

Table A9. Unit values (prices) for the monetary benefit estimation of the ES P3 "Fish cultivated by in-situ aquaculture". (Source: Based on EUMOFAP data).

Species/ products	Applied market price, EUR/kg
Mussel	2-5 EUR (aquaculture sales price – fish retail price)
Trout	6-19 EUR (fish retail/consumption prices (2021) in various countries for various products)
Crustaceans	27 EUR (aquaculture sales price; average for the Baltic Sea from 2018-2020)

RM1 Nutrient regulation

The well-being impacts of the nutrient regulation are estimated accounting the nutrient sequestration sub-service only as the final ES. The monetary estimate is based on avoided costs for nutrient treatment from human activities. Waste Water Treatment Plant (WWTP) abatement costs are used to derive a proxy for the benefits to humans from the nutrient abatement. The approach is based on an assumption that the value of a unit abatement in any pollution source is at least worth the savings obtained when not having to make the similar abatement elsewhere.

The WWTP is used as a benchmark abatement technology. Data on abatement levels and costs are available relatively well. Gren (2008) and Hautakangas et al. (2014) are studies providing such estimates for the Baltic Sea WWTP abatement for both nitrogen and phosphorus. Gren (2008) provides estimates for marginal abatement costs for nitrogen and phosphorus but it is not explicitly shown how they are derived. For nitrogen the estimated marginal abatement costs vary between 12 and 79 €/kg, depending on the country, while they vary for phosphorus between 41 and 330 €/kg. The average costs are not reported. Hautakangas et al. (2014) provides the most transparent methodology for the cost assessment. They estimated the average abatement costs for nitrogen and phosphorus, accounting size of the WWTP and nutrient reduction level. Selected estimates illustrating the variations in these costs are provided in Table A10. When comparing these estimates of the average abatement costs with the results from Gren (2008) on the



marginal abatement costs for similar facilities and removal rates, the results of Hautakangas *et al.* (2014) are slightly lower.

For the purposes of estimating the benefits obtained with the WWTP abatement so far, it would be justified to use the average abatement costs instead of the marginal abatement costs. The marginal abatement cost would give an indirect estimate of the avoided cost of not having to abate the very last unit of the pollutant. However, the essence of the approach is to evaluate how much resources have been allocated on wastewater treatment in total. Hence, the average abatement costs are the correct metric. This is also the approach taken, for instance, by Hernández-Sancho *et al.* (2010).

Of the studies analysed, the values provided by Hautakangas *et al* (2014) were found the most suitable for the sea region assessment. It is justified to use the highest abatement levels to represent the avoided costs. In Finland and Sweden, for instance, such costs would then be 4.7 €/kg for nitrogen and 15.2 €/kg for 90% abatement level for nitrogen and 95% for phosphorus. In many parts of the Baltic Sea, the most effective WWTPs would be better represented by the 70% abatement level for nitrogen and 90% for nitrogen, associated with average abatement costs of 4.3 €/kg for nitrogen and 13.6 €/kg for phosphorus. In 2021 prices these costs would correspond to 6.7 €/kg and 6.1 €/kg for nitrogen and 21.7 €/kg and 19.4 €/kg for phosphorus (Table A10).

Based on the data from Hautakangas et al. (2014) (calculated in 2021 prices) the estimates used for the sea region assessment are 6.5 EUR/kg for nitrogen and 20 EUR/kg for phosphorus. These estimates were compared with assessments from other studies², and it was concluded that they could indicated rather the lower bound of the benefits. It is important to note that these benefit estimates do not take stance to the effects of these pollutants in the environment. They should be seen as the cost benchmark: this, at least, will be benefited by avoiding the abatement from the cheapest possible sources of pollution. The unit values are multiplied by the amount of nitrogen and phosphorus sequestered by the soft bottom sediments (tonnes/year) to calculate the monetary benefits. Confidence in the estimates is moderate, since they are based on an average unit cost for all Baltic Sea countries, but the costs differ in reality depending on various factors (like size of a wastewater treatment plant, the nutrient reduction level).

Table A10. Selected estimates on the average nutrient abatement costs from Hautakangas et al. (2014). [1] 80 000 – 200 000 PE. [2] > 500 000 PE.

Estimates from Hautakangas et al. (2014)		Estimate in 2021 prices
Abatement costs for nitrogen (EUR/kg)		
for middle-size WWTP ^[1] , 70% reduction rate	4.3€	6.1€
for largest-size WWTP ^[2] , 90% reduction rate	4.7€	6.7€
Abatement costs for phosphorus (EUR/kg)		
for middle-size WWTP ^[1] , 90% reduction rate	13.6€	19.4€
for largest-size WWTP ^[2] , 95% reduction rate	15.2€	21.7€

² For instance, the study AKTiiVS (2022) provides the average 16 EUR/kg (for both nutrients), which was calculated based on actual data from all tertiary treatment plants in Latvia (based on data for 2018). Centrum Balticum (2018) used 19 EUR/kg of nitrogen and 86 EUR/kg of phosphorus.



RM3 Carbon sequestration

The well-being impacts of the carbon sequestration are estimated accounting the carbon sequestration sub-service only as the final ES The monetary estimate is based on avoided costs of the damage to human well-being from carbon emissions. The estimate is based on transferring value of "social costs of carbon" from literature.

While there is no market for carbon sequestration in the marine ecosystems, values connected to carbon storage can be taken from carbon markets, national carbon taxes or from estimates inferring the value of stored carbon (or the costs of carbon to society) such as the 'social costs of carbon' (SCC), or the shadow price of carbon. Carbon values are much debated with many estimates for long-run damage costs of climate change and abatement costs. It is recognised that the value is highly uncertain, depending on the underlying climate scenarios, the carbon price used and its change over time, which depends on the assumed price growth rates and discount rates (Armstrong et al. 2019).

The carbon market prices come from charges for carbon emissions that may come in a shape of a carbon tax based on the polluter pays principle or a cap and trade scheme whereby the government introduces permits and companies participate in emissions trading systems, trading carbon emission allowances. The world's largest carbon emission trading scheme is the European Union Emission Trading Scheme (EU ETS). It is designed to steadily reduce the level of carbon emissions over time and therefore the value of an allowance is expected to increase over time. High-Level Commission on Carbon Prices (2017) concludes that the explicit carbon-price level consistent with achieving the Paris temperature target is at least 40-80 USD/t carbon dioxide by 2020 and 50-100 USD/t carbon dioxide by 2030, provided a supportive policy environment is in place.

The question whether a limited market will sufficiently take into account the full cost of carbon emissions has led to substantial work to estimate the SCC. The SCC is the estimate of monetary value of the damage done from the emission of one more ton of carbon at some point in time (Melaku Canu et al., 2015), or, in other words, it is the marginal damage cost of 1 ton of CARBON DIOXIDE emitted. The SCC signals what society should be willing to pay to avoid the future damage caused by incremental carbon emissions. Models developed to estimate the SCC are known as integrated assessment models, which aim to capture the linkages between greenhouse gas emissions, greenhouse gas atmospheric concentrations, temperature change, and monetary costs of climate change damage to society (Melaku Canu et al., 2015).

Value transfer method has been widely applied to value this ES using social/shadow price of carbon dioxide as a proxy of the value (for instance, Melaku Canu et al.). There are studies using SSC (Beaumont et al., 2014; Zarate-Barrera and Maldonado, 2015), but also using both – the carbon market price from EU ETS and the

SSC from literature forming an interval for the carbon value (for instance, in Armstrong *et al.* (2019)).

The estimate used for this assessment is based on value transfer approach using the SSC. The SCC mean value of 54.70 USD (50 EU-R)/t carbon dioxide based on meta-analysis of literature by Wang et al. (2019), gathering 578 estimates of SCC from 58 studies, is used as the basis. Such SCC value is applied also in other studies (in Armstrong et al. (2019)). Such estimate calculated in the 2021 prices makes around 70 EUR/t of carbon dioxide. An interval value of 40-100 EUR/t of carbon dioxide is used for the assessment to account for uncertainties. It is consistent also with the High-Level Commission on Carbon Prices (2017) conclusion on the carbon-price level of 50 – 100 USD/t carbon dioxide by 2030.

The unit values are multiplied by the amount of carbon sequestered by the eelgrass and soft bottom sediments (tonnes/year) in the Baltic Sea to calculate the monetary benefits. Confidence in the estimate is moderate, as it involves transferring the damage costs values from literature.

Cultural ecosystem services related to recreation (C1-C6)

The monetary benefits of cultural ES related to recreation are estimated based on a study, covering Germany, Finland and Latvia (Bertram *et al.*, 2020; Ahtiainen *et al.*, 2022). This study is used since it is the only published recent study, estimating the recreational benefits in relation to the Baltic Sea, based on data for more than one Baltic Sea country. Relevant data from this study are presented in Table A11. The calculated 'consumer surplus' (CS) per person is applied to other Baltic Sea countries using a benefit transfer approach (described in Section 3 and Annex 1.1.1 for the cost of degradation analysis).

The used approach involves several assumptions, which impacts the total calculated benefits:

- The study employed two valuation methods the travel cost method (used in Ahtiainen et al. (2022)) and the contingent behaviour method (used in Bertram et al. (2020)). To follow a conservative approach, the CS estimated by Ahtiainen et al. (2022) is used, which provides lower CS estimates per trip than by Bertram et al. (2020) due to different approaches used for estimating the travel costs and for the econometric modelling.
- CS per person is calculated based on CS per trip, a number of trips per year and a share of users/visitors in total population. Transferring the CS per person estimate to other countries involves assuming a similar number of trips per visitor and a share of users. The available data from surveys in various Baltic Sea countries indicate differences in such data. For the number of trips there can be considerable variations across years as indicated by data from Latvia, where national surveys have been conducted regularly (AKTiiVS, 2022). There is not enough data

Table A11. Data on recreational benefits used for monetary estimation of the benefits of CES related to recreation. (Source: Bertram et al. (2020); Ahtiainen et al. (2022). [1] From Ahtiainen at al. (2022). [2] From Bertram et al (2020).

Study countries		Average number of trips per visitor per year (SD) [2]	Consumer surplus € per visitor per year	Share of visitors in total population [2]	Consumer surplus € per per- son per year (in 2017 prices)
Germany	83.3 [74.2; 92.4]	4.3 (1.0)	358	0.49	176
Finland	79.5 [66.2; 92.9]	10 (3.0)	795	0.76	604
Latvia	66.9 [42.9; 91.0]	4.8 (1.5)	321	0.79	254



- for detailed analysis nor possible value adjustments, accounting differences in the number of trips and share of users. This issue requires further analysis in the future.
- The data are obtained from samples of adult populations, therefore such populations are used also for calculating the total benefits, instead of using the total populations of the countries. The Baltic Sea coastal population is estimated for Russia (5% of the total population).

With the applied assumptions the approach could be seen producing conservative benefit estimates (rather than overestimating them).

A1.3 Cost-benefit analysis assessment

The list of 12 peer-reviewed CBA studies is based on a literature review conducted in the context of this study. The review focused on estimates of environmental values in the Baltic Sea from implementing relevant measures and achieving environmental objectives: either environmental preservation benefits or environmental degradation costs. The papers apply a variety of methods to estimate these values. Studies that calculate abatement costs were excluded, unless said costs were used to calculate the avoided costs from improvements in environmental goods and services.

To identify relevant studies, previous literature searches were used, including the literature list originating from the BONUS ROSEMARIE project (2020). This review included a total of 78 studies following the following criteria:

- 1. Calculate environmental benefits from implementing measures and achieving environmental values
- 2. Published in 2010 or afterwards
- 3. Focus on the Baltic Sea or one of the Baltic Sea countries
- 4. Applied an economic valuation method
- 5. Focus on marine and/or coastal environmental changes and ecosystem service values
- 6. Be either peer-reviewed or grey literature

Each of these studies contained several estimates of benefits for different measures or environmental changes, and each estimate was included in a different row. This yielded a total of 621 benefit values from all 78 studies. Of these 78 studies, 12 conducted cost-benefit analysis.



A1.4 Drivers and driver indicators

Approach to identify drivers

To identify drivers for the HOLAS 3 assessment, a decision-tree-based approach was proposed (Figure A1). The first stage of this approach involves identifying pressures of interest and using them as the basis for identifying drivers (Figure A2). Next, the pressure-activity relationship is used to determine the activities that contribute to the pressures of interest. Based on these main activities, drivers that influence the activity-pressure pairs are determined. It is preferred that topic experts contribute to the driver identification process, and therefore, this process is supported by topic workshops.

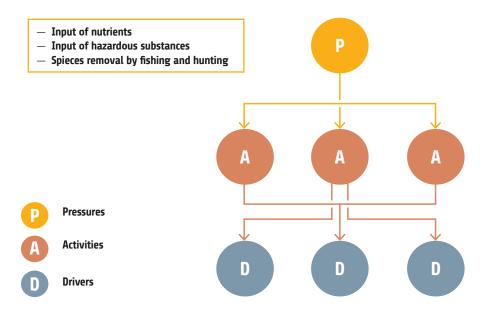


Figure A1. Driver identification approach starting from pressure of interests. Selected proof-of-concept examples for pressures are shown in the blue frame.

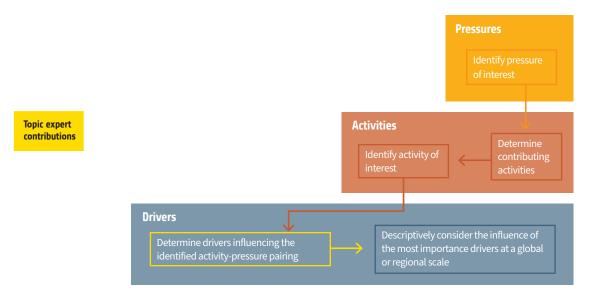


Figure A2. Decision tree including questions and answers for the driver identification process and linking with other DAPSIM components. Stages which would benefit from topic expert contribution are shown in red in the diagram.

Approach to identify driver indicators

To identify potential driver indicators, drivers are filtered based on the questions shown in Figure A3. In the first stage, drivers are checked for quantifiable characteristics. Input from topic experts is preferred in this stage to ensure that the characteristics are justified. If a driver does not have quantifiable characteristics, it is not suitable for creating a specific driver indicator report, but it will be summarized as part of a generic driver summary for all relevant reports. For drivers with quantifiable characteristics, potential indicators are examined by continuing through the decision tree to identify the appropriate use and data.

In the second stage, it is determined whether there is sufficient explanatory value in the potential indicator(s). Again, input from topic experts is preferred. If the answer is no, the driver and indicators are not suitable for specific driver indicator development and their relevance is addressed in the summary. Potential indicators with explanatory value and quantifiable characteristics are listed and analyzed further.

The third stage determines if suitable data on trends for these characteristics is available and can be applied at the Baltic Sea regional scale. If no data is available, a descriptive approach is used. If data is available, these indicators are considered potential driver indicators for further development. These potential indicators and their connections with DAPSIM components are considered and analyzed to provide as much quantitative information as possible from existing data sources.

In HOLAS 3 assessment, a limited number of drivers and driver indicators were explored, focusing on testing the driver – driver indicator methodology using selected proof-of-concept examples. Please note that driver indicators are different than the HELCOM core indicators. A brief summary of relevant drivers of relevance to each topic are provided in driver indicator fact sheets and a more detailed overview of these are available in drivers section in this document.

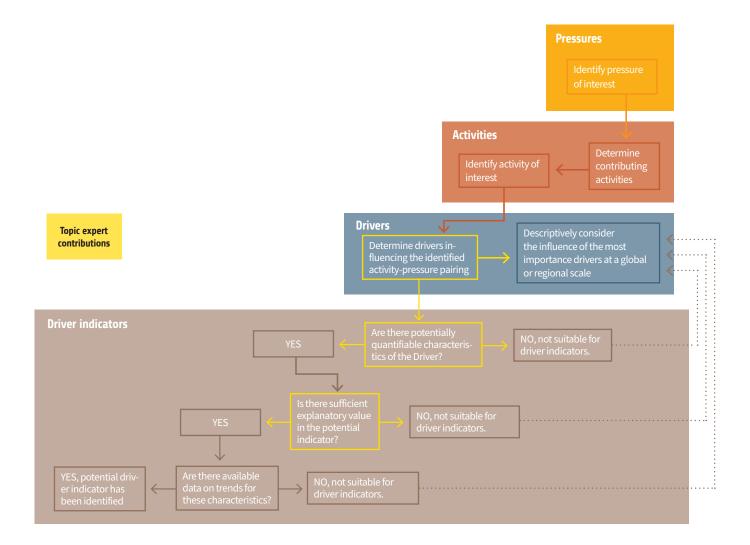


Figure A3. Decision tree including questions and answers for the driver and driver indicator selection process and linking with other DAPSIM components. Stages which would benefit from topic expert contribution are shown in red in the diagram.

Driver indicator fact sheets were developed for the following driver indicators to be used in HOLAS 3 assessment:

1. Agricultural nutrient balance

Agricultural nutrient balance is an indicator set which consists of gross nutrient balance for nitrogen and phosphorus. Animal husbandry and crop production indicators are supporting indicators for the gross nutrient balance indicator and more information on these indicators can be found in the annex section of the driver indicator document. The individual indicators express similar information from different perspectives and are best considered as a group. These indicators can be used as a partial quantified proxy for the drivers of consumer demand, globalization, demographics, subsidies and regulation, and technology adoption.



2. Wastewater treatment

Wastewater treatment is an indicator set which consists of presence and efficiency of wastewater treatment and population distribution indicators. Population distribution indicators are supporting indicators for the presence and efficiency of wastewater treatment indicators. The individual indicators express similar information from different perspectives and are best considered as a group. These indicators can be used as a partial quantified proxy for the drivers of political will, investment, regulation and technology adoption.

3. Total allowable catch

Total allowable catch is a stand-alone driver indicator set which consists of historical excess TACs information. It has high clarity of impact and can be linked to a variety of relevant drivers. This indicator can be used as a quantified proxy for the drivers of political will and socio-economic setting.

4. Fishery operations

Fishery operations is a stand-alone driver indicator set. It has high clarity of impact and can be linked to a variety of relevant drivers. This indicator can be used as a quantified proxy for the drivers of regulations, technology adoption and macroeconomic conditions.

Data sources

The broad range of societal data from Eurostat was reviewed to identify and analyse potential driver indicators. Eurostat office is responsible for collecting and publishing high-quality Europe-wide statistics and indicators that enable comparisons between countries and regions. In general Eurostat aims to develop harmonized definitions and method for European statistics in cooperation with national statistical authorities of European countries. Each driver indicator fact sheet includes data processing section explaining identified and used data sources.

HELCOM indicators and Driver indicators

Driver indicators are considered under the HELCOM indicator manual as part of the cluster of 'supporting indicators'. These indicators are different from the HELCOM core indicators (and the relevant development stages of those, i.e. candidate, pre-core and core) in that they are considered to provide supporting information that can offer further insights or contextual information for HELCOM processes. In addition, indicators categorised as 'Potential causative factors' (i.e. Drivers and Activities), 'Surveillance indicators', or 'Element indicators' (see Indicator manual page 14) are not anticipated to have target values or threshold values but act more in the manner of informative fact sheets that may support contextual understanding, support management or help guide directed action. In addition, the information, data and trends collated in such indicators are anticipated to provide input to other HELCOM processes or steps within the DAPSIM causal framework (e.g. thematic assessments, existing state or pressure indicators, or socio-economic evaluations).

The topic of drivers is relatively new within HELCOM work and the focus in this current process is to develop a workable structure through which examples of driver indicators (i.e. indicators of 'Potential causative factors') can be developed. While a definition of drivers in HELCOM is yet to be agreed, the general understanding is that they could represent both societal aspects and environmental aspects. Environmental aspects, which are not further discussed here, may for example include key environmental

parameters / gradients that has a defined impact on the state of the environment, but are not directly manageable by addressing human activities. HOLAS 3 driver indicator topic, however, focuses on the more manageable part of drivers, i.e., societal, an potential causative factors, and would likely identify quantifiable proxies for these drivers (for example in the form of trends in activities).

The indicators will aim to provide a solid and referenceable material that can support an improved understanding and quantification of the DAPSIM framework (for example for examining sufficiency of measures, socio-economic issues, or as direct input to state indicators), will utilise already available data sources (HELCOM, EU, national, global), are expected to focus on defining trends, and will not apply threshold values. The aim is to produce quantifiable data evaluations where possible, but it is important to note that this is not viable for all elements and some drivers may only be summarized and presented as potential drivers of relevance for the Baltic Sea region. Fact sheets will be produced for the identified drivers with a focus on regional trends and data, though where available and possible to implement sub-regional variation will also be considered.

It is vital to note the following issues when considering this work and further development of it.

- Not all drivers will be purely societal as environmental gradients or conditions can also be direct drivers of marine ecosystems. This division is clarified above in the document and is addressed through different categories of HELCOM indictor, as presented in the HELCOM indicator manual (HELCOM 2020). However, as emphasised by Contracting Parties in the workshops and meetings the ongoing work towards HOLAS 3 will focus on development of indicators addressing societal aspects.
- Drivers are often complex and linked to multiple components
 of the DAPSIM framework including other drivers. Thus, when
 addressing driver indicators, proxies indicative of individual or,
 more typically, combinations of drivers are likely to be required.
 Driver indicators would therefore commonly reflect broad societal trends or concepts or key environmental gradients.
- 3. Not all drivers and their interconnections (or interactions) will be possible to qualify, and certainly not to quantify, in particular where progress on this topic towards HOLAS 3 is envisaged. The discussion and development should support further progress on the concept but also retain the aim of preliminary development on this topic for HOLAS 3 (e.g., where test cases can be developed).
- 4. Driver indicators are more akin to fact sheets (i.e. no threshold values or targets) and would summarise available information and trends that can be used to support a full conceptual understanding of issues via DAPSIM. In addition to the above described benefits, they would also support the state indicators (per indicator topic) by directly providing information of relevance to the section on drivers, activities and pressures (i.e. by providing a reference point of relevance).
- 5. The issue of societal and environmental drivers is addressed separately under HELCOM indicator processes. Drivers related to activities (i.e. societal aspects) are considered under 'Potential causative factor indicators' (Drivers and Activities) whereas environmental drivers are addressed under 'Element indicators' (see page 14 of the HELCOM indicator manual for further details). Both of these indicator categories are classified as supporting indicators. As it was agreed, the work will focus on indirect drivers, i.e., societal drivers, and consequent driver indicators which can support management activities.