Document title	Provisional approval of the HELCOM Science Agenda
Code	5-2
Category	DEC
Agenda Item	5 - Update of the Baltic Sea Action Plan
Submission date	16.11.2020
Submitted by	Executive Secretary
Reference	

Background

Based on the decision by HELCOM 40-2019 to develop a HELCOM Science Agenda (Outcome, para 2.29), HELCOM subsidiary bodies were invited to identify knowledge and science needs to support the implementation of HELCOM agreements. In 2019 the HOD furthermore established a Task Group to prepare the HELCOM Science Agenda report, based on the input from the subsidiary bodies and the tasks and mandate assigned by HELCOM HOD 56-2019 (document 2-6, HOD 56-2019).

The Science Agenda Task Group has held five meetings (Science Agenda TG 1-2020, TG 2-2020, TG 3-2020, TG 4-2020, TG 5-2020) and one intersessional meeting to follow-up on HELCOM 41-2020. Lead countries have been assigned to draft texts for specific topics. The drafting has been carried out by representatives of the Task Group or by national experts involved in HELCOM work that have been appointed by the Task Group representatives.

HELCOM 41-2020 and HOD 58-2020 provided guidance to the further development of the Science Agenda based on the proposals and draft texts prepared by the Science Agenda Task Group (HELCOM 41-2020 para 4.4, HOD 58-2020 para 4.46-4.52). Comments received from countries after HOD 58-2020 have also been considered (Finland, Germany, Sweden).

The Science Agenda has been developed based on the following principles:

- it should focus on the knowledge needed to implement HELCOM agreements, i.e. it should be oriented towards applied knowledge needs;
- it should focus on topics of major importance for HELCOM work and be relevant from a regional perspective;
- it should have a relatively long shelf-time (about 10 years), and as a consequence the highlighted science needs have been formulated relatively broadly, while more specific knowledge needs are included in a separate file as received from HELCOM subsidiary bodies (labelled 'Comprehensive inventory of HELCOM knowledge and science needs');
- the highlighted science needs should be complementary to the BSAP actions, i.e. by providing knowledge that will support the implementation of BSAP actions, but they should not duplicate each other;
- the annexes provide information on how the highlighted science needs are linked to HELCOM agreements and other relevant policies (e.g. UN SDGs, UN Decade of Ocean Science). It should be noted that annexes will be updated and completed once the actions for the updated BSAP have been agreed.

This document includes the report as prepared by the Science Agenda Task Group. A preliminary assessment has been carried out that shows that the Science Agenda and proposed BSAP actions complement each other well. Duplications between the two documents have also been addressed and solutions proposed (document 2-3, TG 5-2020). For those solutions which imply modifications to BSAP actions these will be further considered by the DG BSAP Segment Teams as part of their work in spring 2021. For some topics processes in spring may provide additional input to the Science Agenda report, for example the development of the MSP roadmap. The report is therefore presented for provisional approval. Final editing and harmonization of texts, the addition of a figure to illustrate the links between the topics of the report, and addition of relevant HELCOM agreements remain.

The report has also been submitted to HELCOM Working Groups with the request to add any further suggestions or topics that the Working Groups would like to bring forward to the comprehensive inventory of the HELCOM knowledge and science. This file will be made available as supplementary material to the Science Agenda Report.

Action requested

The Meeting is invited to provisionally approve of the HELCOM Science Agenda, noting that amendments may take place in spring 2021 based on ongoing HELCOM processes.

List of content

Abbreviations and glossary

BSAP	Baltic Sea Action Plan. A comprehensive regional programme of measures and actions to improve the state of the Baltic Sea. The first action plan was adopted in 2007 and it will be updated in 2021.
BWMC	Ballast Water Management Convention
Contracting Parties	Refers to the signatories to the Helsinki Convention, i.e. the nine bordering countries and the EU
EA	Ecosystem approach
GHG	Greenhouse Gases
HELCOM	Governing body of the "Convention on the Protection of the Marine Environment of the Baltic Sea Area," also known as the Helsinki Convention.
HELCOM Ministerial Declaration	Political declarations in which Contracting Parties bind themselves to take further actions to protect the marine environment of the Baltic Sea
HELCOM Nutrient reduction scheme	The HELCOM Nutrient Reduction Scheme is a regional approach to sharing the burden of nutrient reductions to achieve the goal of a Baltic Sea unaffected by eutrophication as agreed by the Baltic Sea countries.
HELCOM Recommendations	HELCOM Recommendations focuses on measures to address certain pollution sources or areas of concern. The Recommendations are to be implemented by the Contracting Parties through their national legislation.
IMO	International Maritime Organization
MARPOL	International Convention for the Prevention of Pollution from Ships
MPA	Marine Protected Area
MSFD	Marine Strategy Framework Directive of the European Union
MSP	Maritime Spatial Planning
NIS	Non-indigenous species
UN SDG	United Nations Sustainable Development Goal

Background

[This text is to be placed e.g. on the back-side of a print-out version of the Science Agenda report]

About HELCOM

The Baltic Marine Environment Protection Commission – also known as the Helsinki Commission (HELCOM) – is an intergovernmental organization and a regional sea convention in the Baltic Sea area, consisting of ten members: the nine Baltic Sea countries Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden, plus the European Union. A platform for environmental policy making at the regional level, HELCOM works for a healthy Baltic Sea.

The Helsinki Convention

The Helsinki Convention was signed in 1974 by the Baltic Sea coastal countries to address the increasing environmental challenges that were having a severe impact on the marine environment. The Helsinki Convention includes the protection of the Baltic Sea from all sources of pollution from land, air and sea. It also commits the signatories to take measures to conserve habitats and biological diversity and to ensure the sustainable use of marine resources.

The Baltic Sea Action Plan

To help reach its environmental objectives, HELCOM established the Baltic Sea Action Plan (BSAP) in 2007. The BSAP is HELCOM's strategic programme of measure and actions to reach a good status of the Baltic Sea's environment. The BSAP will be updated in 2021, to adjust the current actions and to widen its scope on issues such as climate change, marine litter, disturbance to the seabed and underwater noise.

The HELCOM Science Agenda

The HELCOM Science Agenda has been prepared to support the implementation of the BSAP and other HELCOM agreements. It highlights knowledge needs that are seen as essential within the upcoming 10 years. The Science Agenda aims at communicating HELCOM science needs to funding agencies, to inform and inspire scientists to direct their interest towards meeting the knowledge needs in HELCOM, and to increase the interaction between science and policy.

Introduction

Rationale for a HELCOM Science Agenda

HELCOM has set ambitious goals, objectives and agreements to protect and improve the state of the Baltic Sea. The implementation of these commitments involves the application of recent science-based knowledge in wide areas of marine research and related topics. HELCOM commitments include for example development of common targets for reduction of pressures, joint guidelines for sustainable use of resources, implementation of measures, analyses of economic and social aspects of marine management, and assessing the state of the environment, as examples. The preparation of syntheses of available knowledge is often needed to initiate the work and in some cases research projects are required to supply new knowledge for achieving an effective implementation.

This Science Agenda is foremost developed to highlight identified knowledge and science needs to realize existing HELCOM agreements and strategies, such as:

- The Baltic Sea Action Plan – the joint environmental policy of HELCOM countries to reach good environmental status of the Baltic Sea, as updated in 2021 and to be implemented by 2030;
- HELCOM Recommendations – agreements on measures to address certain pollution sources or areas of concern;
- Tasks assigned to HELCOM expert groups – including development of common management guidelines, indicators, proposals for new measures;
- Regular assessments – evaluating the state of the Baltic Sea, identifying pressures from land-based and seabed sources, following-up of management measures.

While HELCOM work and decision-making processes are based on and guided by the best available science, HELCOM is not a scientific body per se and largely depends on advice from a wider scientific community. The main aim of the Science Agenda is therefore to communicate HELCOM science needs to external funding agencies, to inform and inspire scientists to direct their interest and apply for funds towards meeting the knowledge needs in HELCOM, and to increase the interaction between science and policy. The main target audience for the Science Agenda is thus the national authorities engaged in HELCOM work and marine policies in general, national and international science funding bodies, and the scientific community.

Added values of formulating a HELCOM Science Agenda is to concentrate research efforts towards bottle-neck knowledge gaps preventing the achievement of good environmental status in the Baltic Sea. Further, it should stimulate joint regional projects, thereby also increasing potential gains by sharing experience and knowledge transfer between countries. The HELCOM Science Agenda is also linked to the UN Decade of Ocean Science to highlight how the implementation can contribute to building the knowledge needed to reach the UN Sustainable Development Goals by 2030 (see Annex 2).

It is worth noting that the Science Agenda does not address data needs or monitoring programmes per se. These are two key activities of HELCOM work that are governed by the HELCOM 'Data and Information Strategy' and 'Monitoring and Assessment Strategy'. These Strategies are implemented through regular activities and updates of HELCOM monitoring programmes.

How the Science Agenda was developed

The first step of developing the Science Agenda was a request to HELCOM expert groups, networks and Working Groups to identify the knowledge and research needs they have identified as necessary to implement HELCOM agreements in their respective area of work (Annex 1). This survey generated [200 contributions] that are collated in a comprehensive inventory of HELCOM knowledge and research needs and provided as supplementary material to this report.

A Task Group with national representatives was established to prepare a consolidated Science Agenda using the survey results as a starting point. The Task Group has drawn information from the survey contributions but also complemented them, including identification of knowledge needs with a more overarching perspective directed towards the implementation of the Ecosystem Approach, a fundamental principle of HELCOM work.

How to read the Science Agenda

Chapters 1-3 highlights principal HELCOM knowledge and research needs that are required to support the implementation of the updated BSAP by 2030, as well as and other HELCOM agreements, and is structured around priority topics for HELCOM work. Chapter 1, which focuses on the theme 'Biodiversity', presents the knowledge needed to better understand and develop methods to assess the status of and impacts on the Baltic Sea species and habitats and the development of direct measures used to improve their status. Chapter 2 on 'Human dimension' describes science needs related to human activities and the resulting pressures on the Baltic Sea ecosystem and the development of measures to reduce their impact. Chapter 3 on 'Holistic approaches' addresses overarching approaches that can support the goal of reaching a good environmental status, such as the Ecosystem Approach. While the Science Agenda is organized by topics the outlined knowledge needs are interlinked and will all contribute to the implementation of the Ecosystem approach in the Baltic Sea [Figure to be developed]. Finally, Chapter 4 includes a reflection on how the implementation of the Science Agenda can be realized.

The annexes provide associated information to the highlighted knowledge needs. They aim to specify in more detail the type of knowledge that is needed, the HELCOM agreements that will benefit from the knowledge, and how the new knowledge can contribute to the implementation of other ocean related goals. Some of the identified knowledge needs can likely be achieved through short-term desktop studies and synthesis while others will require longer-term research projects. Knowledge that is required in HELCOM within a shorter time-frame than 2030, for example those seen as needed for planned assessments in the short-term, are [will be] indicated in the Annex 2 as appropriate.

1. BIODIVERSITY

The Baltic Sea is renowned for its unique biodiversity, featuring both freshwater and marine species that have adapted to the brackish environment, although the diversity in terms of number of species is relatively low compared to other sea areas. The prevalence of species and communities is largely governed by strong gradients in salinity from north-to-south, coastal-to-offshore, and surface-to-bottom in sub-basins where a halocline prevails. In addition seasonal changes in temperature as well as temporary and permanent oxygen deficits influence the occurrence and composition of species. Benthic habitats and biotopes are also influenced by substrate composition, morphology, exposure, water exchange and depth. When combining these factors in the comparatively small geographic area of the Baltic Sea the result is a mosaic of varied biotopes exhibiting great diversity in function and structure. The Baltic Sea biodiversity is thus dynamic in time and variable in space which also influences the management of human activities.

The species and communities provide many goods and services to the Baltic Sea countries such as food and plant-based resources, but also regulate biological and chemical processes. Biodiversity in good status contributes to ecological resilience, i.e. the capacity of an ecosystem to respond to and recover from disturbances. The composition of species and communities also dictate the structure and function of food webs, another key component determining resilience. The genetic diversity furthermore caters for adaptation to more long-term changes in the environment, a capacity that may be essential considering the projected changes in climate in the Baltic Sea area.

Since the beginning of the 1900's the Baltic Sea is impacted by numerous and increasing number of pressures stemming from human activities as indicated in chapter 2 or the report. Through the Helsinki Convention the Baltic Sea countries have agreed to take all necessary measures to protect the natural habitats, natural processes and biological diversity in the marine and coastal environment of the Baltic Sea area. The protection and mitigating of impacts on biodiversity is a key component of joint HELCOM work, including the common goal to have an ecologically coherent and well managed network of marine protected areas in the Baltic Sea. However, the most recent HELCOM Red List assessments from 2013 indicate 145 species and 17 biotopes or biotope complexes as threatened (HELCOM 2013). The HELCOM State of the Baltic Sea Report from 2018 also shows that many species' groups and communities are not in a good status (HELCOM 2018a).

This chapter focuses on knowledge needs to properly assess the status of the Baltic Sea biodiversity, to understand the effect of pressures on different biological components, and the development and evaluation of management measures that are required to protect and restore biodiversity and food webs. Measures to reduce pressure on the Baltic Sea ecosystem are foremost addressed in the Chapter 2 on 'Human dimension'.

1.1 Species

Species from all parts of flora and fauna in the Baltic Sea have been impacted by human-induced changes in the ecosystem. While the status has improved for several species as a result of well-targeted measures to alleviate these pressures, there are still many species threatened or even at risk of extinction (HELCOM 2013) or having unfavourable living conditions. Baltic Sea populations are disturbed by human activities directly e.g. through habitat deterioration via physical disturbance, and indirectly via contaminants and eutrophication, noise as well as presence of non-indigenous species. Various kinds of bycatch, hunting and fishing are main causes of human induced mortality of marine animals. Awareness is also emerging of marine litter, including microplastics, as a pressure on most of the species while relatively little is known about the impact on specific species and communities. Dedicated research efforts are needed to better

understand the dynamics and distribution of the Baltic Sea species and communities, and the impact of human activities. This is needed to both ensure that human activities can be managed at sustainable levels and to establish effective protection and conservation measures for Baltic Sea species and communities, ultimately securing good status of the environment.

The outlined knowledge needs are relevant for the implementation of numerous HELCOM recommendations related to the protection of threatened species in general as well the specific protection of seals, harbour porpoise and birds (see Box 1).

Highlighted science needs

Species distribution:

- Better knowledge of species distribution, population sizes and ecology, and habitat selection to support precise status assessments and how to best direct management measures.

Indicators and impact of pressures:

- Development and optimization of methodology for the assessment of:
    - age and distribution in coastal fish populations to provision and support ecosystem based management efforts;
    - water bird reproductive success which accounts for the various species groups and provides ecologically relevant information on status across groups, to provision and support ecosystem based management efforts;
    - abundance and distribution for harbour porpoise throughout the species full range to guide conservation and management measures.
    - health aspects which account for spatial and inherent variation between species for seals and harbour porpoise, inclusive of the impact of hazardous substances, to support management efforts.
- Research on impact of noise on marine mammals, fish populations and benthic communities; in particular long-term consequences of masking, disturbance and hearing loss on survival and reproduction of marine mammals, and population-level consequences of impact at different life stages in species with pelagic larvae;
- Research on impact of macrolitter and microplastics on species and communities;
- Evaluation of population level impacts of bycatch of all relevant species.

Conservation plans:

- Better knowledge for development of effective species conservation plans, in particular for marine mammal, bird and fish populations;
- Development of approaches on how to quantify the effectiveness of specific conservation measures for species;
- Research to define precautionary approach levels for seals in their management units.

Box 1. Selected HELCOM Recommendations that would benefit from the highlighted science needs:

17/2	PROTECTION OF HARBOUR PORPOISE IN THE BALTIC SEA AREA
27/28-2	CONSERVATION OF SEALS IN THE BALTIC SEA AREA
34E/1	SAFEGUARDING IMPORTANT BIRD HABITATS AND MIGRATION ROUTES IN THE BALTIC SEA FROM NEGATIVE EFFECTS OF WIND AND WAVE ENERGY PRODUCTION AT SEA
37/2	CONSERVATION OF BALTIC SEA SPECIES CATEGORIZED AS THREATENED ACCORDING TO THE 2013 HELCOM RED LIST

1.2 Habitats

Marine habitats can largely be divided into water column (pelagic) and seabed (benthic) habitats. While these represent two seemingly very different features of the environment, they are tightly interlinked, especially so in the shallow Baltic Sea. Inadequate status of species and communities is closely linked to changes in their physical habitats, while they need intact feeding, resting, and reproduction and nursery areas. For benthic communities and biotopes anthropogenic pressures resulting in loss and disturbance to the seabed, as well as eutrophication, have a strong impact. For the pelagic habitats eutrophication, rising temperatures, potentially enhanced salinity stratification and concomitant higher primary production lead to plankton regime shifts, which in turn leads to oxygen depletion in deeper areas, thereby altering both pelagic and benthic biotopes and overall food web dynamics.

For the implementation of the BSAP and HELCOM Recommendations (Box 2) improved knowledge about interactions between pressures, habitat structures and ecosystem functions is needed.

In addition there is a need for further development of measures to restore habitats which are already deteriorated or which have been lost. Follow up of status as well as the efficiency of conservation efforts furthermore requires development of harmonized monitoring and mapping techniques, as well as standardized assessment and restoration methods.

Highlighted science needs

Habitat mapping:

- Development and testing of criteria for regionally coordinated mapping of habitats/biotopes, taking into consideration the relevant assessment needs, to facilitate data exchange and support national and regional assessments and reporting as well as Maritime Spatial Planning (MSP);
- Development of widely applicable methods and tools to decrease the resource requirement and increase efficiency of habitat mapping.

Pressure-impact assessment:

- Investigations on pressure-response relationships in benthic ecology, such as recovery time of benthic habitats after disturbance, to understand adverse effects of pressures on benthic habitats and to support the definition of threshold values and conservation measures;
- Analysis of historical age and/or size distribution of long-lived species to establish an ecologically relevant baseline to support the setting of appropriate threshold values to indicate where pressures adversely affect benthic communities.

Ecosystem functions:

- Research on links between pelagic and benthic habitats/biotopes and ecosystem functions to better understand the role of benthic and pelagic ecosystem components for ecosystem functioning, to strengthen the ecological relevance of both assessments and management measures;
- Development of criteria for estimating the contribution of pelagic and benthic habitats to ecosystem services to evaluate the benefit of healthy habitats to human well-being;
- Analyses of the role of traits for functioning of pelagic and benthic habitats/biotopes, including the link to food webs, with special focus on a changing climate and oxygen depletion, to improve the holistic aspect of assessments and the causal link between pressures, impact and state.

Habitat restoration:

- Identify areas, as well as develop and improve methods, for the restoration of benthic habitats/biotopes, e.g. habitat-forming species such as seagrass beds, macrophyte stands and reefs, along with improving the understanding of the wider synergistic effects of habitat restoration

efforts, to support the effectiveness of measures to improve biodiversity and nature based-solutions for tackling climate change and its impacts.

Box 2. Selection of HELCOM Recommendations that would benefit from the highlighted science needs:	
40/1	CONSERVATION AND PROTECTION OF MARINE AND COASTAL BIOTOPES, HABITATS AND BIOTOPE COMPLEXES CATEGORIZED AS THREATENED ACCORDING TO THE HELCOM RED LISTS
28E/9	DEVELOPMENT OF BROAD-SCALE MARINE SPATIAL PLANNING PRINCIPLES IN THE BALTIC SEA AREA
35/1	SYSTEM OF COASTAL AND MARINE BALTIC SEA PROTECTED AREAS (HELCOM MPAs[1])

1.3 Food webs

Species diversity is known to be low in the Baltic Sea due to its character as a very young brackish sea with a prehistory as a freshwater lake. A consequence of low species diversity are relatively short food chains, which are more sensitive to disturbance and can be permanently altered by the disappearance of single species. The open sea food web in the Baltic is characterized by a low number of food web interactions driven by a few key species, while the coastal food webs are comparatively more complex and diverse. Functionally diverse marine food webs are the basis of healthy ecosystem, and also indicate the status of biodiversity. Food webs in the Baltic Sea as well as their components – species of flora and fauna – are impacted by various types of pressures either induced directly by human activities or indirectly, e.g. by climate change. The Baltic Sea food webs have at present inadequate status and are deteriorating despite management and governance measures (HELCOM 2018a). Both upper and lower levels of food webs are relevant to consider when assessing changes in predator-prey interactions as well as the larger scale variations of ecosystem functioning.

To improve management of human activities and the conservation efforts in the Baltic Sea, the necessity of understanding the processes between elements of the food webs are stated in several HELCOM reports and planning documents and are reflected as identified science needs.

Highlighted science needs

Knowledge to support food web assessments:

- Better understanding of key food-web states and processes which underlie critical and complex ecosystem dynamics to support assessment of the status of food webs;
- Better understanding of changes in trophic relationships, age categories and species composition of fish caused by fishery activities;
- Better knowledge on benthic - pelagic coupling and associated food web implications from changes in benthic conditions cause by e.g. climate change.

Models to support development of measures

- Development of dynamic food web models, including all relevant food web compartments (e.g fish, mammals and birds), for detection of horizontal (plankton-benthos) and vertical (lower levels-upper levels) interactions, to guide the development of conservation and management measures.

1.4 Marine Protected Areas

Baltic Sea Marine Protected Areas (HELCOM MPAs) locate where the conservation need is most urgent and where the potential benefit is highest. Especially a well-managed and ecologically coherent network is an important tool for fulfilling HELCOM ambitions for a healthy Baltic Sea. Such a network would help

[1] Former HELCOM BSPAs

potentially improve the resilience of the entire ecosystem to external threats such as eutrophication and climate change by protecting biodiversity. Large no-use zones are important aspects of such a network. However, despite large advances in the spatial coverage of MPAs in the Baltic Sea, there is still a lack in implementation of effective conservation measures, partly due to the inadequate understanding of complex ecosystem interactions. The current HELCOM MPA network is not complete nor does it fulfil the requirements for coherence or proper management (HELCOM 2016). In order to fulfil the ambition of HELCOM work on MPAs, as well as the potential of the MPA network to help secure good environmental status, common methods for assessments of management effectiveness need to be developed, as does support to help guide the strategic expansion of the network to improve its ecological coherence.

The science needs would contribute directly to the implementation of HELCOM Recommendation on System of Coastal and Marine Baltic Sea Protected Areas (HELCOM MPAs[2]).

Highlighted science needs

Evaluation of spatial protection measures:

- Development of scientific criteria to be used to identify potential no-take zones, with the aim of limiting the pressure stemming from fishing efforts and improving the state of biodiversity;
- Quantifying the effectiveness of spatial conservation measures, especially the link between measures and change in state, to help guide conservation efforts;
- Development of suitable scientific tools for a regular assessment of the effectiveness of spatial protection measures, i.e. how effective an area or network of areas is, e.g. through its location and extent, proximity to other areas, the species/diversity it hosts, its contribution to ecosystem services etc;
- Establishment of criteria to assess the management effectiveness, both for individual MPAs and the network as a whole, respectively, with the aim of identifying gaps in existing management efforts and improving management both in individual MPAs and across the network.

Ecological coherence

- Establishment of science-based criteria and targets to be used for the HELCOM coherence assessment methodology;
- Identifying parameters which justify the designation of new or expansion of existing MPAs in order to achieve and maintain coherence of the MPA network in relation to climate change;
- Investigating the impact of climate change on protected areas, including modelling benthic habitats/biotopes and species distribution maps for the entire Baltic Sea region under different climate change scenarios, to use as one basis for planning and optimizing the MPA network and ensure coherence in the long term.

[2] Former HELCOM BSPAs.

2. HUMAN DIMENSION

Humans are intractably linked to the Baltic Sea ecosystem through the benefits of its resources and the impacts of human activities on its state. Historic records of cod catches show a viable fishery dating back to late 1500s although intense cod fishery started only in the 1950s. The onset of eutrophication in some coastal areas of the Baltic Sea dates back to circa 1800 CE. During the last century the increasing human population and associated resource demand and the growing development of economic activities have, despite an increasing awareness and environmental regulations, resulted in an unsustainable use of the Baltic Sea as reflected in its current state (HELCOM 2018a).

Many sources of pollutants are land-based and the Baltic Sea, with its slow water exchange with the North Sea (c. 40-50 years), large population in the catchment and proximity to intensive agriculture and industrialized regions, is heavily loaded by nutrients and a broad range of chemical pollutants as well as litter. Sea-based activities are also contributing significantly to the pressures on the sea. Fisheries is the primary cause of human induced mortality of species in the Baltic, including for non-target species such as seals and birds. Shipping is an activity that contributes to many types of pressures, including specific pressures such as introduction of non-indigenous species (NIS) through ballast water and release of hazardous substances that are associated to shipping activities, including oil spills.

For the Baltic Sea, the Helsinki Convention forms the basis for joint protection of the sea from human activities and HELCOM has made many agreements to jointly curb and mitigate the impact of human activities on the environment. An example is the large number of joint Recommendations, including for example limit values for release of substances, guidelines on best available techniques (BAT) and best environmental practices (BEP), agreements on spatial restrictions for certain activities, and much more. While some activities and pressures have been studied for a long time in Baltic Sea the recommendations and other HELCOM commitments still need continuous updates based on latest scientific findings. For pressures such as marine litter and underwater noise, that have been given attention more recently, basic knowledge on sources and development of management measures are still needed.

This chapter focuses on research needs necessary to quantify the sources and levels of pressures as needed, define a sustainable use of marine resources, and to develop and evaluate measures to manage human activities. Better knowledge on expected changes in climate is central since it will need to be considered in the management of all aspects of the Baltic Sea, including in order to adapt policies and to take measures to mitigate the anticipated long-term changes.

2.1 Climate change

Climate change has, and will have, a major impact on the marine environment, from genes to ecosystems, and it poses a growing risk owing to the accelerated pace of change and interactions with other pressures. In the Baltic Sea region climate change will most likely result in increased temperatures and significant changes in other meteorological parameters such as precipitation, wind forcing and cloud cover. This will cause changes in hydrography and circulation in the sea, most likely changes are increased temperature and decrease in ice cover. Furthermore, global sea level rise will affect the Baltic Sea coasts as well as the water exchange with the North Sea. Future salinities are uncertain although more evidence point toward a decrease than an increase, with a potential change in stratification, too. With increasing CO_2 concentration in the atmosphere acidification is expected to increase over time.

These changes will most likely result in significant alterations of all components of the food chain from increased primary production due to faster surface water regeneration to seal population changes due to diminishing sea ice. Changing salinity, most probably decreasing, would have drastic effects on species distribution in the brackish part of the Baltic Sea.

Socioeconomic development is occurring concurrently and, in cases, in response to climate change. Recently, results show that for eutrophication, the global and regional socioeconomic development can be as important as climate change itself in shaping the future Baltic Sea environment.

The ultimate aim of HELCOM work with regards to climate change is to increase and ensure the resilience of the systems of the Baltic Sea to limit the impacts of a changing climate. The challenges presented by marine climate change are by their nature of international concern and the topic is cross-cutting, covering aspects from science to high level policy. To achieve the aim set out under HELCOM, the climate change work within HELCOM focuses on a long-term, multi-disciplinary approach to both understand and communicate the implications of climate change for the marine and coastal environment as well as ensure this information is included in HELCOM policies.

Highlighted science needs

- Further development of regionalized scenarios of climate change effects on the physical environment (hydrography and circulation, sea level, sea ice, morphology) of the Baltic Sea as a basis for a wide range of scientific and managerial assessments, for example, investigations of climate change impacts on the ecosystem and development of coastal adaptation strategies;
- Further development of scenarios that illustrates the impact of multiple global and regional drivers, both socioeconomic development and climate change, on activities and resulting pressure in the Baltic Sea. One example would be; how do changing global food demand together with changed climate influence agriculture in the catchment and the subsequent leakage of nutrients to the sea;
- Development of ways to incorporate climate change aspects to the HELCOM Nutrient Reduction Scheme to ensure that BSAP eutrophication objectives can be reached also under climate change;
- Research on the expected response of biota, biodiversity and ecosystem functioning to climate induced changes of the physical and chemical environment, including responses to water temperature increase and changes to other relevant parameters, for example, salinity, oxygen, sea level and pH.

2.2 Eutrophication

The water quality of almost the entire Baltic Sea is severely impaired to a level that has strongly altered the ecosystem and caused significant benthic habitat loss due to the cumulative effect of a century of high anthropogenic nutrient inputs. The status has not yet improved substantially despite long-term and partly successful efforts to reduce nutrient inputs. Continuous reductions of nutrient inputs are needed to reach the ultimate target: a Baltic Sea unaffected by eutrophication.

Management of Baltic Sea eutrophication is complicated due to the slow response of the system manifested by up to decadal delays from implementation of measures to improved open sea water quality. For this purpose, HELCOM uses results from mathematical models to estimate Maximum Allowable Inputs that are consistent with good environmental status as agreed in HELCOM, and, in addition, there are several studies available on the combined effect of changes in nutrient input and climate change. Less studied on a Baltic Sea scale is the delay and efficiency from implementation of measures on diffuse sources in the catchment to reduction of nutrient inputs via rivers. Increased knowledge on the effects of climate change on eutrophication processes are needed, both in the catchment area and the sea.

There are still demand for the development and implementation of additional measures to reduce the nutrient inputs from waste water, agriculture, shipping and other sources. However, there is also still a lack of knowledge to optimally plan the measures needed to not only achieve reductions of nutrient inputs but to cost-effectively improve eutrophication status in the Baltic Sea.

Highlighted science needs

Input of nutrients:

- Improved and harmonized catchment modelling to determine the sources of nutrient inputs. The selection of appropriate measures to reduce the total nutrient inputs to the Baltic Sea basins can then be supported by quantification of the various anthropogenic sources versus the natural background.

Measures to reduce nutrient input:

- Improved understanding and quantification of nutrient sources that leads to inputs to the sea and quantification of efficiency of measures that can curb these sources. This should result in estimations of reduction potential from different areas and sectors of the countries situated in the catchment area of the Baltic Sea;
- Development of novel efficient and environmentally sustainable techniques and practices to improve nutrient recycling and to minimize nutrient loads from diffuse sources.

Nutrient cycling processes:

- Investigate the obstacles preventing the decrease of nutrient concentrations and contraction of hypoxic/anoxic areas in the sea. This encompasses improving the understanding of how the complex nutrient dynamics, including feedbacks with oxygen conditions, control the legacy of nutrients;
- Improved understanding of the relationships between coastal and offshore eutrophication problems ensuring a solid scientific basis for optimal joint management of coastal and offshore eutrophication. This includes quantification of coastal retention/filter, and understanding and modelling of interactions between the coast and the open Baltic Sea.

2.3 Hazardous Substances

The hazardous substances that enter the Baltic Sea originate from various anthropogenic sources, especially from industries, consumer products, urban areas, submerged munition, agriculture and animal husbandry farms, as well as maritime activities. Just a small fraction of the chemicals that are emitted from society are monitored or screened for. Consequently, the chemical cocktail in the Baltic Sea is not well characterized.

The most recent status assessment addressing hazardous substances indicates that status is not good overall, and that due to the persistent nature of several of these substances (or groups of substances) it is likely that contamination will remain a significant pressure for an extended period. The majority of the chemicals used as indicators are legacy pollutants which are strictly regulated at regional and/or global level and have been substituted by other less well-known compounds. In addition to comprehending the overall pool of potentially harmful substances entering the Baltic Sea, further efforts are warranted to assess the biological effect of the total chemical load on human health and ecosystems, including transformation products and in combination with other stressors. More knowledge regarding sources, emissions and dominant transport processes are needed to develop efficient measures that can reduce the chemical pollution.

[Reference to HELCOM agreements/strategy that will benefit from closing the knowledge gap]

Highlighted science needs

Input of hazardous substances:

- Improved knowledge on use patterns and emissions of hazardous substances from various sources, both land-and sea-based, and modelling of relative importance of different transport routes to support development of efficient measures targeting chemical contamination of the Baltic Sea in general, such as advanced wastewater- and storm water treatment, and identification of specific substance groups of concern;
- Retrospective temporal trend analysis of emissions and environmental concentrations, e.g. through historic deposition in sediments or samples in biota banks, to assess efficiency of implemented measures and interactions with multiple pressures and stressors - both legacy contaminants and contaminants of emerging concern;
- Improved knowledge on submerged munition and its integrity (e.g. status of corrosion, leakage of the hazardous substances) per location including development of a risk assessment approach for marine environment (e.g. in biota, if applicable in sediment and water).

Status and effects of contaminants:

- Development and harmonization of monitoring methods based on biological effects, including bioassays for different endpoints at various levels and species targeting specific modes of action, that capture the impact of the total chemical mixture in the marine environment;
- Development of methods that can link observed effects with causing agents, i.e. identification of *substances/mixtures* or tracing *human activities* releasing a broad range of contaminants mainly responsible for the observed effects;
- Research on fate and transport of chemical contaminants in the marine environment under impact by multiple stressors, including eutrophication and climate change, and the effect that chemical contaminants (individual or mixtures) exert on key biological functions such as biogeochemical processes governing carbon and nutrient cycling.

2.4 Marine litter

Pollution of the marine environment by litter and in particular plastics is a global problem that was recognized already in the early 1970s while research in the Baltic started in early 2000s. Studies on the amount, type and distribution of macro- and microlitter are ongoing, including sampling of water, bottom sediments and the coastline/beaches, and common guidelines for beach litter surveys have been compiled. However, due to varying methodologies in water and sediment sampling, sample processing and laboratory analyses applied in different research institutes, the collected data especially for microlitter is not fully comparable yet. In addition indicator species need to be defined in order to monitor and assess harm caused by marine litter, especially with view to ingestion and entanglement.

HELCOM has adopted a Regional Action Plan on marine litter, in order to fulfil the overall commitment to significantly reduce marine litter by 2025 compared with 2015. However, although there are already a few studies on marine litter in the Baltic region, due to the relatively short period of monitoring there is not enough reliable data on the scale of the problem and understanding of the most efficient ways of its mitigation, and thus there is still need for further research. This includes to improve knowledge on the sources of litter as well as on how to sample and assess the presence and impact of litter.

Highlighted science needs

Development of monitoring:

- Development of harmonized cost-efficient methodologies for monitoring microplastics in relevant compartments and biota, including field sampling, sample pre-treatment and plastics identification in laboratory, to support the establishment of a regional monitoring programme.
- Developing a monitoring system for microplastics in biological organisms: identification of microplastics in the Baltic Sea food chain - from zooplankton to marine mammals and birds and humans.

Input, impact and fate of litter:

- Further identification and quantification of land- and sea-based sources and pathways of macro-, mesolitter and microplastics, including identification of the sources at sea and on land;
- Better understanding of the degradation and fragmentation processes of macro- to meso- and microplastics to understand the importance of the formation of secondary microplastics and potentially nanoplastics and related releases of additives into the marine environment and biota;
- Research on the interactions of environmental conditions and natural factors like currents, winds, bottom topography, transfer in biota, river runoff, etc. and their influence on marine litter distribution;
- Quantification of socioeconomic effects including human health implications from marine litter.

Mitigation measures:

- Evaluation of effectiveness and adaptation to regional needs of management actions, e.g. bans of plastics, improved wastewater treatment to remove microplastics, improved waste coastal waste management, application of Extended Producer Responsibility schemes, awareness programmes, etc.;

2.5 Underwater noise

Sound propagates effectively in water and various marine animals rely strongly on sound for communication, orientation and foraging. Noise from anthropogenic activities can also propagate far away from the source and affect communication (masking) and behaviour of animals, and if intense enough, even cause hearing loss, tissue damage and, in worst case, lead to death, in particular if no mitigation measures are applied. Anthropogenic underwater noise is grouped into *impulsive* noise from e.g. explosions, seismic surveys, pile driving and sonars or and *continuous* noise, from ships and marine infrastructure (oil and gas platforms, offshore wind turbines etc.). Because the sources are well known less uncertainty relates to the pressure on the ecosystem, whereas the largest uncertainties relate to the impact. Assessing impact requires knowledge of how anthropogenic noise affects animals in their natural habitat, knowledge of the actual noise exposure of the animals, and knowledge of their abundance and spatiotemporal distribution. As a prerequisite to assessing impacts, it is also necessary to have proper knowledge of the spatiotemporal distribution of anthropogenic sources and their acoustic properties. In cases, where an impact is evident, there is a subsequent need for development and testing the effectiveness of mitigation measures as well as the assessment of their potential negative side effects.

Science needs related to impact on animals (individuals as well as populations) are addressed in detail in the section on “Species”. Science needs related to mitigating noise emissions from commercial shipping are addressed in the section on “Shipping”. This section focuses on the noise itself, as a pressure factor and source of impact on marine ecosystems. The science needs closely reflect the needs arising from the measures committed to in the HELCOM Regional Action Plan for underwater noise [currently in draft].

Highlighted science needs

Impact of impulsive noise:

- Expand knowledge of pressures from sources currently not monitored, such as echosounders, sonars and sub-bottom profilers, to support assessment of impact both on small scale (EIAs on specific projects) and large scale (sub-basin scale);
- Explore long-term consequences of noise exposure to individuals and populations (see also Species section);
- Development and refinement methods to quantify impact from impulsive noise sources on animal populations, moving away from interim risk-based indicators to true impact indicators.

Sources and impact of continuous low frequency noise:

- Improvement of methods for long-term acoustic monitoring, including modelling in shallow waters, taking into consideration work done in relevant fora;
- Develop or adapt methods to include contributions from smaller, recreational vessels and static sources in modelling;
- Expand knowledge of metabolic and physiological consequences of disturbances caused by vessel noise;
- Expand knowledge of the impact of continuous low frequency noise on individuals and populations (see also Species section);
- Develop and refine methods to quantify impact from continuous noise sources on animal populations, moving away from interim risk-based indicators to true impact indicators;
- Encourage studies on the impact of climate change on the underwater soundscapes (direct and indirect effects of changes in sea level, hydrography and ice conditions) in order to improve the precision of forecasted scenarios involving underwater noise sources.

Mitigation measures:

- Develop or adapt effective noise abatement methods applicable to underwater explosions and/or alternatives to detonation;
- Develop and test technical and operational measures to reduce impact from other impulsive sources.

2.6 Non-indigenous species

The spread of non-indigenous species (NIS) is a global problem that affects most ecosystems and is among the greatest threats to biodiversity. The damage to biodiversity caused by the spread of NIS is often irreversible as aquatic NIS are impossible to eradicate after they have established themselves in the ecosystem. The shallow and enclosed nature of the Baltic Sea, the young age of the sea and the brackish conditions - which respectively result in low species diversity and consequently incomplete occupancy of niches - in combination with the intense marine traffic, makes the Baltic Sea prone to the introduction and settlement of NIS.

Marine NIS most often enter the Baltic Sea with the ballast water of ships or as biofouling on the ship hulls and harbors and ports are therefore hot spots for the introduction of non-indigenous species. The main vectors for freshwater NIS are canals, shipping and aquaculture.

The introduction of NIS through shipping is addressed in the dedicated section on Shipping while this section is focused on the general needs to improve knowledge for the purpose of assessing the introduction and status of NIS and the impacts of NIS on other ecosystem components.

Highlighted science needs

Assessment of NIS:

- Development of reliable species identification methods, including molecular methods such as eDNA and developing DNA barcodes for Baltic Sea NIS, which would improve monitoring efforts;
- Comprehensive understanding of the dynamics of spread for NIS within the Baltic Sea, to support the assessment of abundance, spatial distribution, and establishment, and, where necessary, the implementation of preventative measures.

Impacts of NIS:

- Better understanding of the effects of small NIS taxa such as protozoa, bacteria, and viruses. They remain unrecognized, undetected and they have no priority in surveying NIS, and knowledge on their impact is thus limited;
- Development of methodologies to quantify the impact of NIS on the ecosystem functioning, including for communities, biological process and habitats, and on its carrying capacity and resilience. Improved knowledge would support the development of an indicator on adverse effects by NIS;
- Research on the impacts of NIS on ecosystem services, health and other socio-economic aspects.

2.7 Shipping

During the last decades, the number and size of ships sailing the Baltic Sea have continuously increased and thereby their potential pressures on marine environment and atmosphere.

Impacts of shipping are caused e.g. by air emissions, sewage, introductions of non-indigenous species (NIS), underwater noise and accidental or illegal discharges of oil. In addition, shipping accidents may occur which can lead to significant environmental threats. In order to minimize environmental harm, many regulations have been adopted and partially already entered into force. Given the unique and sensitive environmental conditions of the Baltic Sea, it is designated by the IMO as Special Area under MARPOL Annexes I, IV and V and Sulphur and NOx emission control area under MARPOL Annex VI. Thus, it is provided with a higher level of protection than other sea areas.

Some of the pressures have already been addressed, others require the development and implementation of new measures. In case of shipping, HELCOM aims at ensuring efficient and harmonized regional implementation of IMO regulations (e.g. MARPOL and BWMC). In addition, initiatives supporting the work at the international level are regionally developed. Further research activities are essential to advance and improve environmental standards, monitoring and assessment, as well as to evaluate the effectiveness of potential mitigation measures and to develop innovative sustainable technologies.

Highlighted science needs

Pressures and impacts from shipping:

- Quantification of hazardous substances like PAHs and heavy metals from discharge water from Exhaust Gas Cleaning Systems (EGCS) to assess the need for more stringent regulation;
- Tools for real-time information and smart monitoring of underwater noise emission;
- High resolution data on shipping activities for cumulative impact assessment;
- Quantification of the amount of oil released to the Baltic Sea from small but continuous emissions of mineral oils and assessment of the environmental effects to assess the need for more stringent regulation;
- Evaluation of effects and consequences of sewage discharges from cargo vessels;
- Evaluation and estimation of volumes of discharges of harmful cargo residues into the Baltic Sea;

- Research on impact and management of food waste from ships in the Baltic Sea;
- Evaluation of effects on the marine environment of discharge water from Exhaust Gas Cleaning Systems (EGCS).

Development of measures to reduce pressures from shipping:

- Development of technical- and management options and evaluation of impacts of grey water discharges from vessels, in particular from passenger and cruise ships;
- Identification and feasibility assessment of Best available Technique (BAT) and Best Environmental Practice (BEP) for underwater noise reduction;
- Contribute to the research and development activities in the context of the IMO´s initial GHG strategy;
- Development of risk assessment and standards with respect to in-water cleaning (IWC) of commercial ships and leisure boats.

Implementation and enforcement of measures to reduce pressures from shipping:

- Research on indicative sampling of ballast water for BWMC D-2 compliance monitoring in the context of the IMO BWM Experience Building Phase;
- Mapping of future needs of oil combatting capacity with a view to ensuring operational functionality of oil combatting operations regardless of season;
- Further analysis and consideration of the human factor in the maritime traffic risk forecasting system to make it more reliable;
- Research on the importance of electronic failures, human-machine interaction, and the autonomous ship concept.

2.8 Fisheries

The Baltic Sea hosts a unique combination of marine and freshwater species and habitats, and sustains diverse fisheries targeting a variety of species. The largest share belongs to herring, sprat, and cod. The ecosystem is characterized by a poor conservation status of several fish stocks, resulting in low catch quotas. Moreover, gillnets-fisheries generate considerable amounts of bycatch, including endangered species, and bottom trawling causes disturbance to sensitive benthic habitats. A great proportion of the fleet in the Baltic Sea consists of small-scale fisheries. There is currently too few data available in order to quantitatively assess resulting impacts of fisheries in the Baltic Sea. An advanced reporting as well as research on fisheries impacts and mitigation measures is needed to improve fisheries management that together with other environmental factors impact the fish stocks enables reaching a good status of habitats and species and achieving ecologically sustainable fisheries.

[Mention as relevant specific HELCOM agreement/strategies that are relevant of this section.]

Highlighted science needs

Enhanced mapping of fishing impacts:

- Intensified research on bycaught species of all métiers to assess bycatch rates of seabirds, marine mammals and protected fish species;
- Applied research on alternative methods for assessing and managing commercial fish stocks for their sustainable use;
- Research on monitoring methods and management of coastal fisheries and fish species with little or no economic value, including freshwater populations, to preserve local fish stocks.

Advancement of bycatch mitigation measures:

- Intensified research on bycaught species of all métiers in order to advance bycatch mitigation measures;
- Development of new technical measures, alternative gear and modifications to existing gear to decrease bycatch of seabirds, marine mammals and protected fish species.

Evaluation of the effectiveness of measures:

- Analysis and determination of the recovery process of benthic habitats and species in areas closed for fishing to assess management effectiveness;
- Calculation/modelling of socio-economic aspects of fisheries affecting benthic habitats and fisheries management options throughout different métiers, performance of cost-benefit analyses;
- Evaluation of management measures (e.g. spatial-temporal closures of fisheries, No-take areas) to avoid or reduce bycatch of threatened and declining species.

3. HOLISTIC APPROACHES

The previous chapters have focused on the knowledge and research needs related to specific species, communities, pressures and activities. For the sake of this document these topics have been presented separately, in reality they are all linked and successful management requires consideration of all of these aspects in a holistic way.

HELCOM work is based on the 'Ecosystem approach' (EA), a concept originally developed under the UN Convention on Biological Diversity. HELCOM furthermore promotes 'Ecosystem based management' (EBM) of human activities which incorporates the entire ecosystem into management, including humans, with the aim of achieving long term sustainable use of the ecosystem and required protection of the marine environment. Essential information for implementing these holistic approaches includes knowledge on the distribution and magnitude of pressures and their impacts on the ecosystem. Economic and social analyses provide a link between the ecosystem and the human dimension, for example through analyses on the benefits in terms of ecosystem services and revenues from economic sectors. The implementation of EA and EBM furthermore require that that the concepts are translated into practice. For this purpose, Maritime Spatial Planning (MSP) can provide a tool for arranging and integrating different uses of the sea.

Management according to EA principles is still very much developing and evaluations of its realization and achievements is largely missing, in the Baltic Sea region and worldwide.

This chapters captures knowledge and research needs that are specifically linked to holistic approaches while highlighted science needs of integrated character are also represented under the other chapters, for example Food webs and Climate change.

3.1 Ecosystem approach

HELCOM and OSPAR agreed on the following common definition of the Ecosystem Approach for their convention areas at their Joint Ministerial Meeting 2003 in Bremen, Germany: *"the comprehensive integrated management of human activities based on the best available scientific knowledge about the ecosystem and its dynamics, in order to identify and take action on influences which are critical to the health of marine ecosystems, thereby achieving sustainable use of ecosystem goods and services and maintenance of ecosystem integrity"*. This includes the application of the precautionary principle.
The EA is advanced in HELCOM through the implementation of the Baltic Sea Action Plan.

Although the EA is a frequently used term and many principles for its implementation have been developed, there are many unresolved issues that require in-depth scientific investigation, in particular for the marine environment.

Highlighted science needs:

- Evaluation of in what way and how far the EA, i.e. the management of human activities in the Baltic Sea Region, has been implemented;
- Establishing rules of procedure and approaches for implementation of the precautionary principle in the EA, ensuring compatibility with other assessments;
- Investigate how the provisions of the Paris Agreement, as response to the threat of climate change, can be incorporated into the EA concept for the Baltic Sea;
- Evaluation of approaches, measures and instruments to improve the state of the Baltic Sea towards good environmental status through application of the EA;
- Develop and improve Decision Support Tools that can perform qualitative and quantitative analysis to support implementation of the EA to management of human activities.

3.2 Maritime Spatial Planning

In 2010, the Ecosystem Approach was incorporated into 10 common HELCOM and VASAB Maritime Spatial Planning (MSP) principles, where it is considered as an overarching principle. In 2016 a HELCOM and VASAB Guideline was developed to address the implementation of an ecosystem-based approach in Maritime Spatial Planning in the Baltic Sea area. In recent years the implementation of the EA in MSP has been further developed through joint regional projects (e.g. Baltic SCOPE 2015-2017 and Pan Baltic SCOPE 2018-2019).

The Baltic Sea countries' MSPs apply the EA on a general level as is expected in the HELCOM MSP roadmap 2013-2020 and in the EU directive on MSP, but none of the countries can be said to have taken the EA as the cornerstone of their MSP. A factor that remains to be developed, despite significant progress in research and conceptual aspects of ecosystem-based approach in the Maritime Spatial Planning field, is fully-fledged test cases of the ecosystem-based approach in the MSP. Such test cases should be supported with strong, multidisciplinary research to facilitate future practical implementation of the EA. Such research would also support to the implementation of the updated HELCOM MSP Roadmap that is likely to have a strong emphasis on the EA [Note: the Roadmap is still under development].

Highlighted science needs

- Identify an appropriate collection of transparent spatial planning tools for a comprehensive consideration of ecosystem components;
- Investigate how Maritime Spatial Planning, applying the guiding principles of the EA, can incorporate independent sectoral plans into a regional and holistic plan that is fully aligned with conservation and good status objectives in the Baltic Sea region;
- Establish processes with an ultimate goal of a comprehensive marine, ecosystem-oriented planning for the Baltic Sea area;
- Develop guidance to the application of ecosystem-based approach in MSP to protect biotopes of high ecological value and sensitivity [from draft MSP roadmap; to be adjusted if revised]
- Develop a common methodology for indicating areas of high natural value, as a basis for steering harmful activities away from such areas [from draft MSP roadmap; to be adjusted if revised].

3.3 Spatial pressure and impact assessments

Human activities in the Baltic Sea and its catchment area create a variety of pressures, potentially leading to negative impacts on the environment. If each of the pressures is considered individually, they may appear to be at levels that do not cause harm to the environment. However, when considering their spatial and temporal distribution, their relation to specific ecosystem components, or in a cumulative manner, their impact may be considerable. Spatial pressure and impacts assessments can be used as a tool for implementing holistic environmental management and to support sustainable development e.g. to identify the spatial and temporal distribution of pressures and impacts, whether a pressure affecting an area is direct or indirect, the proportional contribution of a pressure to the impact on a particular site or feature, as well as providing a link back to the activity or activities the pressure originally stems from. This in turn can be used to inform the planning and implementation of measures, prioritising management activities, support the use of the precautionary approach and as a risk assessment tool. It also provides a good platform for regional cooperation and transboundary work, including for spatial planning efforts.

HELCOM Ministers agreed in their Brussels Ministerial Declaration 2018 to improve the understanding of impacts of human activities (HELCOM 2018b), including the cumulative effects, on the ecosystem and to use this information for strengthening the implementation of ecosystem-based management. For spatial

pressure and impact assessment to reach its full potential there is a need for improved understanding of the links between activities, pressures and impacts, in particular the sensitivities of various ecosystem components to these pressures, but also for technical development.

Highlighted science needs

- Improve spatial modelling of activities, pressures and ecosystem components underlying the impact assessment to enable improved resolution of the pressure and impact maps, thus increasing their usability for management;
- Develop a reliable method for validation of the results of a pressure or impact assessment to improve the confidence of the assessments and by extension their applicability in management;
- Improved understanding of the sensitivity of ecosystem components to various pressure, thus strengthening the link between pressure and change in state to support assessment, management actions and the setting of realistic conservation targets;
- Improved understanding of the accumulation and synergistic or antagonistic effect of several pressure overlapping in space and time, to better guide management measures and provide context to results of other assessments.

3.4 Economic and social analyses

Economic and social analyses are needed to fully apply the EA in the Baltic Sea and to support the sustainable use of marine resources. They provide a set of tools for examining the interlinkages between the ecosystem and economic and social system, and contribute to ecosystem-based marine management, maritime spatial planning, pollution mitigation, and integration and implementation of effective measures and policies. The concept of ecosystem services includes measurable benefits that people can obtain from ecosystems and therefore is used as a tool in the economic and social analyses. Identification and valuation of ecosystem services provides an option to quantify the impacts of ecosystems on human welfare, find the gaps and contribute to information pool necessary for sustainable use of these services. As a part of the World Ocean, the Baltic Sea supplies numerous ecosystem services that provide benefits for economic activities and existence.

Although the process of employing economic and social analysis in HELCOM assessments has already started, research is still needed for implementing the HELCOM decisions such as the Ministerial Declaration 2018 (HELCOM 2018b) the Roadmap for HELCOM work on economic and social analyses .

Highlighted science needs

- Better understanding of how the status of the marine environment is related to changes in economic activities and how these are distributed spatially to support ecosystem-based management of human activities and maritime spatial planning;
- Evaluation of the costs, effects and benefits of measures and policies to support the development of effective new measures and policies, e.g. the BSAP;
- Research on the linkage of marine state components to ecosystem services, related values and benefits to provide information on the welfare impacts of ecosystem changes and support the development of effective policies, e.g. the BSAP;
- Developing approaches for the integrated assessment of ecosystem services to provide more information on the links between the ecosystem and the social-economic system to support the implementation of the EA and marine policies;
- Development and application of quantitative criteria to describe ecosystem services to improve knowledge on the extent of ecosystem services in the Baltic Sea and their changes;

- Development and testing of approaches and tools for marine ecosystem accounting to provide additional information on the linkages between the ecosystem and economic system and improve the consideration of ecosystem values in decision-making, to support more effective policies.
- Research on obstacles for the implementation of HELCOM agreements, including aspects related to governance, actors, sector activities and factors that influence the behaviour of private citizens, reflecting the diversity in geographic and socioeconomic characteristics across the region, with the aim to generate tools to support transformative change.

4 How the HELCOM Science Agenda can be implemented

Direct involvement of HELCOM

The main part of the knowledge enhancing activities takes place in the scientific institutions and universities in the HELCOM countries. HELCOM has however some possibilities for direct involvement in science-based projects through external funding mechanisms. HELCOM can for example act as coordinator of projects with partners from the Contracting Parties, an approach that has been taken in a number of projects financed by the EU through calls linked to the Marine Strategy Framework Directive. On a number of occasions HELCOM has furthermore acted as partner in regionally coordinated projects that have been financed through EU Interreg programmes. In the case of carrying out joint assessments or to take forward key issues, such as the development of indicators or pollution load compilations, HELCOM can also initiate projects based on funding by the HELCOM countries.

The Science Agenda provides a tool for prioritizing internal activities and for directing efforts for development of applications with HELCOM as coordinator or partners. The possibilities for HELCOM to be directly involved in science projects is however limited in terms of possibility to apply, administer and coordinate projects.

External initiatives

Since the implementation of the major part of the Science Agenda will depend on external funding resources and participation of the experts from the Member countries, it is foremost a way of communicating HELCOM science needs to the bodies external to HELCOM. The Science Agenda therefore aims at:

- encouraging scientists to apply for research projects linked to the highlighted knowledge needs,
- inviting external funding bodies to consider HELCOM knowledge and science needs in their planning of calls for application, including
    - national authorities and agencies and private foundations that are funding research in the field of environment and sustainable development,
    - organisations responsible for regional funding programmes focusing on the marine environment such as the European Commission and JPI Oceans,
- increasing interaction between policy and science.

HELCOM will also provide the Science Agenda as a contribution to the UN Decade of Ocean Science which will run from 2021-2030. The aim of the UN initiative is to create a common ocean science framework that can support countries in achieving the UN Sustainable Development Goals and turn the scientific knowledge and understanding into effective actions to support a sustainable development. In Annex 2 to this report the links between the highlighted knowledge and research to the strategic objectives of the Decade of Ocean Science can be found. By supporting the UN Decade of Ocean Science, Baltic Sea countries can provide the necessary scientific underpinnings for future HELCOM work, including the implementation of the updated BSAP and UN Sustainable Development Goals.

Many of the HELCOM knowledge and science needs are linked to the development of common approaches and a common basis for developing new and implementing existing HELCOM agreements. Funding programmes that support regional projects are therefore essential since they give scientist from several Baltic Sea countries the opportunity to work together already in the formulation phase of projects, implementation, as well as in the communication with stakeholders such as HELCOM. The joint Baltic Sea research and development programme BONUS, funded by the EU and research funding institutes of the eight EU Member States of the Baltic Rea region, significantly boosted knowledge on the Baltic Sea social-

ecological system during its implementation (2011-2017). The ongoing project 'The Baltic and North Sea Coordination and Support Action BANOS', develops the foundation for a new research and innovation programme with similar funding mechanisms but now geared towards both Baltic Sea and North Sea. If realized the identified objectives of the new programme can likely support part of the HELCOM Science Agenda, in particular the more research demanding knowledge needs while some of the more applied and short-term knowledge needs are less likely to fit the scope and criteria of the envisioned BANOS research program. *[Note: y time of approval of the Science Agenda more information may be available on the tentative start of such programme*]. A funding programme oriented towards both Baltic Sea and North Sea will also support further joint studies and development work between the two regional seas, activities that are strongly encouraged by the Commissions of the respective marine convention.

Proposed further reading

Selected reference list.

HELCOM 2013. HELCOM Red List of Baltic Sea species in danger of becoming extinct. Baltic Sea Environment Proceedings 140.

HELCOM 2013. Red List of Baltic Sea underwater biotopes, habitats and biotope complexes. Baltic Sea Environment Proceedings 138.

HELCOM 2016. Ecological coherence assessment of the Marine Protected Area network in the Baltic Sea. Baltic Sea Environment Proceedings 148.

HELCOM 2018a. State of the Baltic Sea – Second HELCOM holistic assessment 2011-2014. Baltic Sea Environment Proceedings 155.

HELCOM 2018b. 2018 HELCOM Ministerial Meeting, Burssels. https://helcom.fi/media/documents/HELCOM-Brussels-Ministerial-Declaration.pdf

HELCOM 2020. Roadmap for continued HELCOM work on economic and social analyses. https://helcom.fi/helcom-at-work/groups/gear/helcom-esa-network/

Annex 1 Countries and HELCOM subsidiary bodies that have contributed

The Science Agenda is largely based on a survey that was distributed to all HELCOM expert networks, task groups and expert projects in spring and autumn 2019. Contributions were received according to the list below. The survey results have also been discussed at HELCOM Working Group meetings with the opportunity to complement the proposals.

- EN Benthic (benthic species and habitats),
- EN ESA (economic and social aspects), prepared by the chair, Finland, Estonia, Latvia, Lithuania and Germany,
- JWG Birds, prepared by the chair and with input from Germany and Sweden,
- EN Noise, prepared by the chair, based on the implementation of the draft HELCOM roadmap on underwater noise,
- EG MAMA (mammals),
- RedCore/PLC (input of nutrients),
- EN Hazardous substances,
- IN EUTRO (eutrophication),
- FISH-PRO project (coastal fish).
- Denmark with regard to non-indigenous species and marine litter,
- Germany (Bfn), focusing on monitoring and nature conservation, with additional input from Germany related to non-indigenous species from shipping,
- Poland, with regard to agriculture,
- Finland, with regard to MPAs.

Annex 2, Links to HELCOM agreements and UN commitments

[Note that annexes are still to be finalized; to provide a link to concepts and BSAP commitments]

The examples given in this annex include mapping of the knowledge and science needs vs

- type of knowledge needs (e.g. if they are related to indicators, pressure targets, development of measures, models etc),
- link to HELCOM agreements and activities,
- link to the DPSIR concept,
- link to the UN Decade of Ocean Science and UN Sustainable development goals.

The aim is to provide more information to scientists that may have an interest in applying for funds related to the Science Agenda but also for further HELCOM work by linking the Science Agenda to current concepts and ongoing activities. This mapping is carried out against the level of highlighted science needs as presented in the main report.

Terms used in the mapping:

D(A)PSIR:

The term "Activities (A)" has been added to the DPSIR scheme as it is a relevant aspect for purpose of HELCOM work while underlying "Drivers" are currently more rarely addressed. The designations in the tables are linked to the type of knowledge/research while in a broader sense the knowledge needs may be linked to additional aspects of the DPSIR scheme.

D=Drivers
A=Activities
P=Pressures
S=State
S/I= Impacts on state components
I=Social impacts (here also including development and implementation of social and economic analyses to support marine management)
R=Response (measures, adaption to changes, here also including development, implementation and evaluation of management tools)

Objectives UN Decade of Ocean Science:

The link to the UN Decade of Ocean Science is made to the level of "objectives" that have been defined i.e.:

- A clean ocean where sources of pollution are identified and removed
- A healthy and resilient ocean where marine ecosystems are mapped and protected
- A predictable ocean where society has the capacity to understand current and future ocean conditions
- A safe ocean where people are protected from ocean hazards
- A sustainably harvested ocean ensuring the provision of food supply
- A transparent ocean with open access to data, information and technologies

UN Sustainable Development Goals (UN SDGs)

Targets of the UN SDGs with an immediate link to the Science Agenda are listed below. Full list of SDGs can found at https://www.un.org/sustainabledevelopment/sustainable-development-goals/

9.4 By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities

12.4 By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment

12.5 By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse

13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries

13.2 Integrate climate change measures into national policies, strategies and planning

14.1 By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution

14.2 By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans

14.3 Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels

14.4 By 2020, effectively regulate harvesting and end overfishing, illegal, unreported and unregulated fishing and destructive fishing practices and implement science-based management plans, in order to restore fish stocks in the shortest time feasible, at least to levels that can produce maximum sustainable yield as determined by their biological characteristics

14.5 By 2020, conserve at least 10 per cent of coastal and marine areas, consistent with national and international law and based on the best available scientific information

14c Enhance the conservation and sustainable use of oceans and their resources by implementing international law as reflected in UNCLOS, which provides the legal framework for the conservation and sustainable use of oceans and their resources, as recalled in paragraph 158 of The Future We Want

Species

Highlighted knowledge needs	Type	Implementation of	DPSIR	UN Decade of Ocean Science	UN SDG
Better knowledge of species distribution, population sizes and ecology, and habitat selection to support precise status assessments and how to best direct management measures.	Distribution, species attributes	Rec 17/2 (Harbour Porpoise Rec 27/28-2 (Seals) Rec 34E/1 (Bird Habitats Rec 37/2 (threatened species)	S	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2,14.5
Development and optimization of methodology for the assessment of: • age and distribution in coastal fish populations to provision and support ecosystem based management efforts; • water bird reproductive success which accounts for the various species groups and provides ecologically relevant information on status across groups, to provision and support ecosystem based management efforts; • abundance and distribution for harbour porpoise throughout the species full range to guide conservation and management measures. • health which account for spatial and inherent variation between species for seals and harbour porpoise, inclusive of the impact of hazardous substances, to support management efforts.	Indicators, status	Indicator development	S	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2, 14.5
Research on impact of noise on marine mammals, fish populations and benthic communities; in particular long-term consequences of masking, disturbance and hearing loss on survival and reproduction of marine mammals, and population-level consequences of impact at different life stages in species with pelagic larvae.	Impacts, status	Indicator development	P, S/I	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed A clean ocean where sources of pollution are identified and reduced or removed	14.2
Research on impact of macrolitter and microplastics on species and communities.	Impacts, status	Indicator development	P, S/I	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed A clean ocean where sources of pollution are identified and reduced or removed	14.2
Evaluation of population level impacts of bycatch of all relevant species.	Impacts, status	Indicator development	P, S/I	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2

				A clean ocean where sources of pollution are identified and reduced or removed	
Better knowledge for development of effective species conservation plans, in particular for marine mammal, bird and fish populations.	Measures, development	Rec 37/2 (threatened species)	R	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2
Development of approaches on how to quantify the effectiveness of specific conservation measures for species.	Measures, evaluation	Rec 37/2 (threatened species)	R	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2
Research to define precautionary approach levels for seals in their management units.	Conservation, threshold value	Rec 27/28-2 (Seals)	S, R	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2

Habitats

Highlighted knowledge needs	**Type**	**Implementation of**	**DPSIR**	**UN Decade of Ocean Science**	**UN SDG**
Develop and test criteria for regionally coordinated mapping of habitats/biotopes, taking into consideration the relevant assessment needs, to facilitate data exchange and support national and regional assessments and reporting as well as Maritime Spatial Planning (MSP).	Mapping, methods	Rec 40/1 (threatened habitats)	S	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2
Develop widely applicable methods and tools to decrease the resource requirement and increase efficiency of habitat mapping.	Mapping, methods	Rec 40/1 (threatened habitats)	S	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2
Investigations on pressure-response relationships in benthic ecology, such as recovery time of benthic habitats after disturbance, to understand adverse effects of pressures on benthic habitats and to support the definition of threshold values and conservation measure.s	Impacts, status	MD 2018 (CHECK formulation) Rec 40/1 (threatened habitats)	P, S/I	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2
Analysis of historical age and/or size distribution of long-lived species to establish an ecologically relevant baseline to support the setting of appropriate threshold values to indicate where pressures adversely affect benthic communities.	Impacts, status Species attributes	Indicator development	P, S/I, S	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2
Research on links between pelagic and benthic habitats/biotopes and ecosystem functions to better understand the role of benthic and pelagic ecosystem components for ecosystem functioning, to strengthen the ecological relevance of both assessments and measures.	Ecosystem interactions	Rec 40/1 (threatened habitats)	S	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2
Development of criteria for estimating the contribution of pelagic and benthic habitats to ecosystem services to	Ecosystem services	MD 2018, Contribution to ESA developments	(I)*	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2

evaluate the benefit of healthy habitats to human well-being.					
Analyses of the role of traits for functioning of pelagic and benthic habitats/biotopes, including the link to food webs, with special focus on a changing climate and oxygen depletion, to improve the holistic aspect of assessments and the causal link between pressures, impact and state.	Impacts, status Functional traits,	Indicator development	P, S/I, S	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2
Identify areas, as well as develop and improve methods, for the restoration of benthic habitats/biotopes, e.g. habitat-forming species such as seagrass beds, macrophyte stands and reefs, along with improving the understanding of the wider synergistic effects of habitat restoration efforts, to support the effectiveness of measures to improve biodiversity and nature based-solutions for tackling climate change and its impacts.	Measures, development	Rec 40/1 (threatened habitats)	R	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2

*The knowledge need is not linked to social impacts per se but can contribute to the development of social economic impact analyses.

Food webs

Highlighted knowledge needs	Type	Implementation of	DPSIR	UN Decade of Ocean Science	UN SDG
Better understanding of key food-web states and processes which underlie critical and complex ecosystem dynamics to support assessment of the status of food webs.	Indicators, status	Indicator development	S	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2
Better understanding of changes in trophic relationships, age categories and species composition of fish caused by fishery activities.	Impacts, fisheries		P, S, S/I	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed A productive ocean supporting sustainable food supply and a sustainable ocean economy	14.2, 14.4.
Better knowledge on benthic - pelagic coupling and associated food web implications from changes in benthic conditions from e.g. climate change.	Impacts, interactions		P, S, S/I	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2
Development of dynamic food web models, including all relevant food web compartments (e.g fish, mammals and birds), for detection of horizontal (plankton-benthos) and vertical (lower levels- upper levels) interactions, to guide the development of conservation and management measures.	Models		S, R	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed A predicted ocean where society understands and can respond to changing ocean conditions	14.2

Marine protected areas

Highlighted knowledge needs	Type	Implementation of	DPSIR	UN Decade of Ocean Science	UN SDG
Development of scientific criteria to be used to identify potential no-take zones, with the aim of limiting pressure stemming from fishing efforts and improving the state of biodiversity.	Method development, measures	Rec 35/1 (MPAs)	R	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2, 14.5
Quantifying the effectiveness of spatial conservation measures, especially the link between measures and change in state, to help guide conservation efforts.	Method development, measures	Rec 35/1 (MPAs)	R	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2, 14.5
Development of suitable scientific tools for a regular assessment of the effectiveness of spatial protection measures, i.e. how effective an area or network of areas is, e.g. through its location and extent, proximity to other areas, the species/diversity it hosts, its contribution of services etc.	Method development, evaluation of measures	Rec 35/1 (MPAs)	R	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2, 14.5
Establishment of criteria to assess the management effectiveness, both for individual MPAs and the network as a whole, respectively, with the aim of identifying gaps in existing management efforts and improving management both in individual MPAs and across the network.	Method development, evaluation of measures	Rec 35/1 (MPAs)	R	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2, 14.5
Establishment of science-based criteria and targets to be used for the HELCOM coherence assessment methodology.	Method development, assessment	Rec 35/1 (MPAs)	R	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2, 14.5
Identifying parameters which justify the designation of new or expansion of existing MPAs in order to achieve and maintain coherence of the MPA network in relation to climate change.	Measures, development	Rec 35/1 (MPAs)	R	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2, 14.5
Investigating the impact of climate change on protected areas, including modelling benthic habitats/biotopes and species distribution maps for the entire Baltic Sea region under different climate change scenarios, to use as one basis for planning and optimizing the MPA network and ensure coherence in the long term.	Impacts, climate change	Rec 35/1 (MPAs)	P, S/I, R	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2, 14.5

Climate change

Highlighted knowledge needs	Type	Implementation of	DPSIR	UN Decade of Ocean Science	UN SDG
Further development of regionalized scenarios of climate change effects on the physical environment (hydrography and circulation, sea level, sea ice, morphology) of the Baltic Sea as a basis for a wide range of scientific and managerial assessments, for example, investigations of climate change impacts on the ecosystem and development of coastal adaptation strategies.	Scenario development, climate change		P, R	A predicted ocean where society understands and can respond to changing ocean conditions A safe ocean where life and livelihoods are protected from ocean-related hazards	13.2, 13,2, 14.3
Further development of scenarios that illustrates the impact of multiple global and regional drivers, both socioeconomic development and climate change, on activities and resulting pressure in the Baltic Sea. One example would be; how do changing global food demand together with changed climate influence agriculture in the catchment and the subsequent leakage of nutrients to the sea.	Scenario development, cumulative pressures		D, A, P, S, I	A predicted ocean where society understands and can respond to changing ocean conditions	13,2, 14.3
Development of ways to incorporate climate change aspects to the HELCOM Nutrient Reduction Scheme to ensure that BSAP eutrophication objectives can be reached also under climate change.	Adaptation of policy		P, R	A predicted ocean where society understands and can respond to changing ocean conditions	13.2, 14.3
Research on the expected response of biota, biodiversity and ecosystem functioning to climate induced changes of the physical and chemical environment, including responses to water temperature increase and changes to other relevant parameters, for example, salinity, oxygen, sea level and pH.	Response, ecosystem		P, S/I	A predicted ocean where society understands and can respond to changing ocean conditions	14.3

Eutrophication

Highlighted knowledge needs	Type	Implementation of	DPSIR	UN Decade of Ocean Science	UN SDG
Improved and harmonized catchment modelling to determine the sources of nutrient inputs. The selection of appropriate measures to reduce the total nutrient inputs to the Baltic Sea basins can then be supported by quantification of the various anthropogenic sources versus the natural background.	Models, input of nutrients	MAI/CART	P	A clean ocean where sources of pollution are identified and reduced or removed	14.1
Improved understanding and quantification of nutrient sources that leads to inputs to the sea and quantification	Activity-pressure links	MAI/CART	A, P	A clean ocean where sources of pollution are identified and reduced or removed	14.1

of efficiency of measures that can curb these sources. This should result in estimations of reduction potential from different areas and sectors of the countries situating in the catchment area of the Baltic Sea.				A predicted ocean where society understands and can respond to changing ocean conditions	
Development of novel efficient and environmentally sustainable techniques and practices to improve nutrient recycling and to minimize nutrient loads from diffuse sources.	Measures, development		R	A clean ocean where sources of pollution are identified and reduced or removed	14.1
Investigate the obstacles preventing the decrease of nutrient concentrations and contraction of hypoxic/anoxic areas in the sea. This encompasses improving understanding of how the complex nutrient dynamics including feedbacks with oxygen conditions control the legacy of nutrients.	Models, ecosystem response	MAI/CART	P, S/I	A clean ocean where sources of pollution are identified and reduced or removed	14.1
Improved understanding of the relationships between coastal and offshore eutrophication problems ensuring a solid scientific basis for optimal joint management of coastal and offshore eutrophication. This includes quantification of coastal retention/filter, and understanding and modelling of interactions between the coast and the open Baltic Sea.	Models, ecosystem interactions	MAI/CART	P, S/I	A clean ocean where sources of pollution are identified and reduced or removed	14.1

*The knowledge need is not linked to social impacts per se but can contribute to the development of social economic impact analyses.

Hazardous substances

Highlighted knowledge needs	Type	Implementation of	DPSIR	UN Decade of Ocean Science	UN SDG
Improved knowledge on use patterns and emissions of hazardous substances from various sources, both land-and sea-based, and modelling of relative importance of different transport routes to support development of efficient measures targeting chemical contamination of the Baltic Sea in general, such as advanced wastewater- and storm water treatment, and identification of specific substance groups of concern.	Models, sources of pressure		P, R	A clean ocean where sources of pollution are identified and reduced or removed	12.4
Retrospective temporal trend analysis of emissions and environmental concentrations to assess efficiency of implemented measures and interactions with multiple pressures and stressors - both legacy contaminants and contaminants of emerging concern.	Level of pressure Effectiveness of measures		P	A clean ocean where sources of pollution are identified and reduced or removed	12.4
Improved knowledge on submerged munition and its integrity (e.g. status of corrosion, leakage of the hazardous substances) per location including development of a risk	Mapping, risk assessment		P	A clean ocean where sources of pollution are identified and reduced or removed	12.4

assessment approach for marine environment (e.g. in biota, if applicable in sediment and water).					
Development and harmonization of monitoring methods based on biological effects that capture impact of the total chemical mixture in the marine environment (e.g. specific bioassays related to the respective mode of action of the chemicals) and can function as an early warning leading to further assessment of substances (screening for the substances which are giving the signal in the bioassay test) or activities releasing a broad range of contaminants mainly responsible for the effects.	Impact on biota, method development		S/I	A clean ocean where sources of pollution are identified and reduced or removed	12.4
Research on transport and transformation of chemical contaminants in the marine environment under impact by multiple stressors, including eutrophication and climate change, and the effect that chemical contaminants (individual or mixtures) exert on key biological functions such as biogeochemical processes governing carbon and nutrient cycling.	Impact on biogeochemical processes. multiple stressors,		P, S/I	A clean ocean where sources of pollution are identified and reduced or removed A predicted ocean where society understands and can respond to changing ocean conditions	12.4

Marine litter

Highlighted knowledge needs	**Type**	**Implementation of**	**DPSIR**	**UN Decade of Ocean Science**	**UN SDG**
Development of harmonized cost-efficient methodologies for monitoring microplastics in relevant compartments and biota, including field sampling, sample pre-treatment and plastics identification in laboratory, to support the establishment of a regional monitoring programme.	Method development, status	Rec 36/1 (marine litter)	S	A clean ocean where sources of pollution are identified and reduced or removed	12.5,
Developing a monitoring system for microplastics in biological organisms: identification of microplastics in the Baltic Sea food chain - from zooplankton to marine mammals and birds and humans.	Method development, status	Rec 36/1 (marine litter)	S	A clean ocean where sources of pollution are identified and reduced or removed	12.5
Further identification and quantification of land- and sea-based sources and pathways of macro-, mesolitter and microplastics, including identification of the sources at sea and on land.	Input of pressure, sources	Rec 36/1 (marine litter)	P	A clean ocean where sources of pollution are identified and reduced or removed	12.4, 12.5, 14.1
Better understanding of the degradation and fragmentation processes of macro- to meso- and microplastics to understand the importance of the formation of secondary microplastics and potentially nanoplastics and related releases of additives into the marine environment and biota.	Input of pressure, sources	Rec 36/1 (marine litter)	P	A clean ocean where sources of pollution are identified and reduced or removed	12.4, 12.5. 14.1

Research on the interactions of environmental conditions and natural factors like currents, winds, bottom topography, transfer in biota, river runoff, etc. and their influence on marine litter distribution.	Input of pressure, distribution	Rec 36/1 (marine litter)	P	A clean ocean where sources of pollution are identified and reduced or removed	12.4, 12.5, 14.1
Evaluation of effectiveness and adaptation to regional needs of management actions, e.g. bans of plastics, improved wastewater treatment to remove microplastics, improved waste coastal waste management, application of Extended Producer Responsibility schemes, awareness programmes, etc.	Measures	Rec 36/1 (marine litter)	R	A clean ocean where sources of pollution are identified and reduced or removed A predicted ocean where society understands and can respond to changing ocean conditions	12.4, 12.5, 14.1
Quantification of socioeconomic effects including human health implications from marine litter.	Impacts, socio-economic	Rec 36/1 (marine litter)	I	A clean ocean where sources of pollution are identified and reduced or removed	12.4, 12.5, 14.1

Underwater noise

Highlighted knowledge needs	Type	Implementation of	DPSIR	UN Decade of Ocean Science	UN SDG
Expand knowledge of pressures from sources currently not monitored, such as echosounders, sonars and sub-bottom profilers, to support assessment of impact both on small scale (EIAs on specific projects) and large scale (sub-basin scale).	Input of pressure, sources	[Regional Action Plan on underwater noise]	P, S, S/I	A clean ocean where sources of pollution are identified and reduced or removed	14.2
Explore long-term consequences of noise exposure to individuals and populations (see also Species section);	Impacts, status	[Regional Action Plan on underwater noise]	P, S, S/I	A clean ocean where sources of pollution are identified and reduced or removed	14.2
Develop and refine methods to quantify impact from impulsive noise sources on animal populations, moving away from interim risk-based indicators to true impact indicators.	Impacts, status	Indicator	P, S, S/I	A clean ocean where sources of pollution are identified and reduced or removed	14.2
Improvement of methods for long-term acoustic monitoring, including modelling in shallow waters, taking into consideration work done in TG-Noise.	Methods, monitoring	[Regional Action Plan on underwater noise]	P	A clean ocean where sources of pollution are identified and reduced or removed	14.2
Develop or adapt methods to include contributions from smaller, recreational vessels and static sources in modelling.	Modelling, sources	[Regional Action Plan on underwater noise]	P	A clean ocean where sources of pollution are identified and reduced or removed	14.2
Expand knowledge of metabolic and physiological consequences of disturbances caused by vessel noise.	Impacts, status		P, S, S/I	A clean ocean where sources of pollution are identified and reduced or removed	14.2
Expand knowledge of the impact of continuous low frequency noise on individuals and populations (see also Species section).	Impacts, status	Indicator	P, S, S/I	A clean ocean where sources of pollution are identified and reduced or removed	14.2
Develop and refine methods to quantify impact from continuous noise sources on animal populations, moving	Impacts, status	Indicator	P, S, S/I	A clean ocean where sources of pollution are identified and reduced or removed	14.2

away from interim risk-based indicators to true impact indicators.					
Encourage studies on the impact of climate change on the underwater soundscapes (direct and indirect effects of changes in sea level, hydrography and ice conditions) in order to improve the precision of forecasted scenarios involving underwater noise sources.	Impacts, climate change	[Regional Action Plan on underwater noise]	P, S, S/I	A clean ocean where sources of pollution are identified and reduced or removed	14.2
Develop or adapt effective noise abatement methods applicable to underwater explosions and/or alternatives to detonation.	Measures, development	[Regional Action Plan on underwater noise]	R	A clean ocean where sources of pollution are identified and reduced or removed	14.2
Develop and test technical and operational measures to reduce impact from other impulsive sources.	Measures, development	[Regional Action Plan on underwater noise]	R	A clean ocean where sources of pollution are identified and reduced or removed	14.2

Non-indigenous species

Highlighted knowledge needs	**Type**	**Implementation of**	**DPSIR**	**UN Decade of Ocean Science**	**UN SDG**
Development of reliable species identification methods, including molecular methods such as eDNA and developing DNA barcodes for Baltic Sea NIS, which would improve monitoring efforts.	Method development Level of pressure		P, S	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2
Comprehensive understanding of the dynamics of spread for NIS within the Baltic Sea, to support the assessment of abundance, spatial distribution, and establishment, and, where necessary, the implementation of preventative measures.	Distribution, pressure	Indicator	P	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2
Better understanding of the effects of small NIS taxa such as protozoa, bacteria, and viruses. They remain unrecognized, undetected and they have no priority in surveying NIS, and knowledge on their impact is thus limited.	Impacts, on ecosystem		P, S/I	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2
Development of methodologies to quantify the impact of NIS on the ecosystem functioning, including for communities, biological process and habitats, and on its carrying capacity and resilience. Improved knowledge would support the development of an indicator on adverse effects by NIS.	Impacts, on ecosystem		P, S/I	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2
Research on the impacts of NIS on ecosystem services, health and other socio-economic aspects.	Impacts, socio-economic		I	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2

Shipping

Highlighted knowledge needs	Type	Implementation of	DPSIR	UN Decade of Ocean Science	UN SDG
Quantification of hazardous substances like PAHs and heavy metals from discharge water from Exhaust Gas Cleaning Systems (EGCS) to assess the need for more stringent regulation	Level of pressure		P	A clean ocean where sources of pollution are identified and reduced or removed	12.4
Tools for real-time information and smart monitoring of underwater noise emission;	Level of pressure		P	A clean ocean where sources of pollution are identified and reduced or removed	14.2
High resolution data on shipping activities for cumulative impact assessment;	Activity, spatial distribution		A	A clean ocean where sources of pollution are identified and reduced or removed	
Quantification of the amount of oil released to the Baltic Sea from small but continuous emissions of mineral oils and assessment of the environmental effects to assess the need for more stringent regulation.	Level of pressure		P	A clean ocean where sources of pollution are identified and reduced or removed	12.4
Evaluation of effects and consequences of sewage discharges from cargo vessels;	Impacts		P, S/I	A clean ocean where sources of pollution are identified and reduced or removed	12.4, 14.1
Research on impact and management of food waste from ships in the Baltic Sea;	Impacts		P, S/I	A clean ocean where sources of pollution are identified and reduced or removed	12.4, 14.1
Evaluation of effects on the marine environment of discharge water from Exhaust Gas Cleaning Systems (EGCS).	Impacts		P, S/I		
Identification and feasibility assessment of Best available Technique (BAT) and Best Environmental Practice (BEP) for underwater noise reduction;	Measures		R	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2
Development of technical- and management options and evaluation of impacts of grey water discharges from vessels, in particular from passenger and cruise ships	Impacts, Measures		S/I, R	A clean ocean where sources of pollution are identified and reduced or removed	12.4, 14.1
Contribute to the research and development activities in the context of the IMO´s initial GHG strategy;	Pressure		P	A clean ocean where sources of pollution are identified and reduced or removed	9.4, 12.4, 14.1
Development of risk assessment and standards with respect to in-water cleaning (IWC) of commercial ships and leisure boats.	Risk assessment, IWC		P	A clean ocean where sources of pollution are identified and reduced or removed	14.2, 14c
Research on indicative sampling of ballast water for BWMC D-2 compliance monitoring in the context of the IMO BWM Experience Building Phase;	Methods development, pressure		P	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2, 14c
Mapping of future needs of oil combatting capacity with a view to ensuring operational functionality of oil combatting operations regardless of season				A safe ocean where life and livelihoods are protected from ocean-related hazards	

Further analysis and consideration of the human factor in the maritime traffic risk forecasting system to make it more reliable;				A safe ocean where life and livelihoods are protected from ocean-related hazards	
Research on the importance of electronic failures, human-machine interaction, and the autonomous ship concept.					

Fisheries

Highlighted knowledge needs	Type	Implementation of	DPSIR	UN Decade of Ocean Science	UN SDG
Intensified research on bycaught species of all métiers to assess bycatch rates of seabirds, marine mammals and protected fish species.	Mapping and collation of information on activity Level of pressure	Roadmap on fisheries data	A, P	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed A productive ocean supporting sustainable food supply and a sustainable ocean economy	14.4, 14.2
Applied research on alternative methods for assessing and managing commercial fish stocks for their sustainable use.	Management, methods development		P, S/I, R	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed A productive ocean supporting sustainable food supply and a sustainable ocean economy	14.4, 14.2
Research on monitoring methods and management of coastal fisheries and fish species with little or no economic value, including freshwater populations, to preserve local fish stocks.	Monitoring/Management, methods development		S/I, R	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed A productive ocean supporting sustainable food supply and a sustainable ocean economy	14.4, 14.2
Intensified research on bycaught species of all métiers in order to advance bycatch mitigation measures.	Mapping Measures, evaluation	Roadmap on fisheries data	P, R	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed A productive ocean supporting sustainable food supply and a sustainable ocean economy	14.4, 14.2
Development and testing of new technical measures, alternative gear and modifications to existing gear to decrease bycatch of seabirds, marine mammals and protected fish species.	Measures, development		R	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed A productive ocean supporting sustainable food supply and a sustainable ocean economy	14.4, 14.2
Analysis of the recovery process of benthic habitats and species in areas closed for fishing to assess management effectiveness.	Measures, evaluation	HELCOM Rec 35/1	R	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2, 14.4
Calculation/modelling of socio-economic aspects of fisheries affecting benthic habitats and fisheries management options throughout different métiers, performance of cost-benefit analyses.	Socio-economic impacts		I	A productive ocean supporting sustainable food supply and a sustainable ocean economy	14.2, 14.4

Evaluation of management measures (e.g. spatial-temporal closures of fisheries, No-take areas) to avoid or reduce bycatch of threatened and declining species.	Measures, evaluation	HELCOM Rec 35/1	R	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2

Ecosystem approach

Highlighted knowledge needs	Type	Implementation of	DPSIR	UN Decade of Ocean Science	UN SDG
Evaluation of in what way and how far the EA, i.e. the management of human activities in the Baltic Sea Region, has been implemented.	Management, evaluation	BSAP	R	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2
Establishing rules of procedure and approaches for implementation of the precautionary principle in the EA, ensuring compatibility with other assessments.	Management, implementation	BSAP	R	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2
Investigate how the provisions of the Paris Agreement, as response to the threat of climate change, can be incorporated into the EA concept for the Baltic Sea.	Management, implementation	BSAP	R	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2
Evaluation of approaches, measures and instruments to improve the state of the Baltic Sea towards good environmental status through application of the EA.	Management tools, evaluation	BSAP	R	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2
Develop and improve Decision Support Tools that can perform qualitative and quantitative analysis to support implementation of the EA to management of human activities.	Management tools, evaluations	BSAP	R	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	

Maritime Spatial Planning

Highlighted knowledge needs	Type	Implementation of	DPSIR	UN Decade of Ocean Science	UN SDG
Identify an appropriate collection of transparent spatial planning tools for a comprehensive consideration of ecosystem components.	Management tool	MSP roadmap	R	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2
Investigate how Maritime Spatial Planning, applying the guiding principles of the EA, can incorporate independent sectoral plans into a regional and holistic plan that is fully aligned with conservation and good status objectives in the Baltic Sea region.	Management tools	MSP roadmap	R	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2
Establish processes with an ultimate goal of a comprehensive marine, ecosystem-oriented planning for the Baltic Sea area.	Management, process	MSP roadmap	R	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2

Develop guidance to the application of ecosystem-based approach in MSP to protect biotopes of high ecological value and sensitivity [from draft MSP roadmap; to be adjusted if revised].	Management guidance Protection of biotopes	MSP roadmap	R	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2
Develop a common methodology for indicating areas of high natural value, as a basis for steering harmful activities away from such areas [from draft MSP roadmap; to be adjusted if revised].	Management tool Identification of high natural values	MSP roadmap	R	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2

Spatial pressure and impacts assessment

Highlighted knowledge needs	Type	Implementation of	DPSIR	UN Decade of Ocean Science	UN SDG
Improve spatial modelling to enable improved resolution of the pressure and impact maps, thus increasing their usability for management.	Modelling, pressures and impacts	Assessment tool	P, S/I	A clean ocean where sources of pollution are identified and reduced or removed	
Develop a reliable method for validation of the results of a pressure or impact assessment to improve the confidence of the assessments and by extension their applicability in management.	Pressure and impacts assessment, validation	Assessment tool	P, S/I	A clean ocean where sources of pollution are identified and reduced or removed	
Improved understanding of the sensitivity of ecosystem components to various pressure, thus strengthening the link between pressure and change in state to support assessment, management actions and the setting of realistic conservation targets.	Impacts, sensitivity of ecosystem components	Assessment tool	P, S/I, S	A clean ocean where sources of pollution are identified and reduced or removed	
Improved understanding of the accumulation and synergistic or antagonistic effect of several pressure overlapping in space and time, to better guide management measures and provide context to results of other assessments.	Cumulative impacts	Assessment tool	P, S/I	A clean ocean where sources of pollution are identified and reduced or removed	

Economic and social analyses

Highlighted knowledge needs	Type	Implementation of	DPSIR	UN Decade of Ocean Science	UN SDG
Better understanding how the status of the marine environment is related to changes in economic activities and how these are distributed spatially to support	Link status-activity	ESA Roadmap	A, S	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2

ecosystem-based management of human activities and maritime spatial planning.					
Evaluation of the costs, effects and benefits of measures and policies to support the development of effective new measures and policies, e.g. the BSAP.	Measures, evaluation	ESA Roadmap, BSAP	R	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed A productive ocean supporting sustainable food supply and a sustainable ocean economy	14.2
Research on the linkage of marine state components to ecosystem services, related values and benefits to provide information on the welfare impacts of ecosystem changes and support the development of effective policies e.g. the BSAP.	Link status-ecosystem services	ESA Roadmap	S/I, I	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed A predicted ocean where society understands and can respond to changing ocean conditions	14.2
Developing approaches for the integrated assessment of ecosystem services to provide more information on the links between the ecosystem and the social-economic system to support the implementation of the EA and marine policies.	Methods development, ecosystem services	ESA Roadmap	(I)*	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2
Development of quantitative criteria to describe ecosystem services to improve knowledge on the extent of ecosystem services in the Baltic Sea and their changes.	Methods development, ecosystem services	ESA Roadmap	(I)*	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2
Development and testing of approaches and tools for marine ecosystem accounting to provide additional information on the linkages between the ecosystem and economic system and improve the consideration of ecosystem values in decision-making, to support more effective policies.	Methods development, ecosystem accounting	ESA Roadmap, BSAP	(I)*	A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed	14.2
Research on obstacles for the implementation of HELCOM agreements, including aspects related to governance, actors, sector activities and factors that influence the behaviour of private citizens, reflecting the diversity in geographic and socioeconomic characteristics across the region, with the aim to generate tools to support transformative change.	Measures, implementation	BSAP	R	A predicted ocean where society understands and can respond to changing ocean conditions	14.2

*The knowledge need is not linked to social impacts per se but can contribute to the development of social economic analyses.